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# *Analytical Study of Concrete Pavement Behavior*



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This report presents research undertaken to develop a methodology to study concrete pavement behavior under dead load, temperature and a moving dynamic vehicle. The methodology developed considers concrete crack formation and corresponding stiffness degradation, soil nonlinear behavior and failure theory, vehicle vibration and velocity effect and the pavement roughness.

The results obtained with the methodology could not be compared with other results because there is not any other comparable tools available, but the general behavior obtained seemed very logical for all the cases studied.

From the examples studied it can be concluded that there is not an increase on dynamic response with an increase in the random generated roughness amplitude. Also, for the slab studied there is a decrease in the magnitude of the dynamic response with an increase in vehicle velocity. (KR)


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# TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

# LIST OF FIGURES

## LIST OF FIGURES (Cont.)



## LIST OF TABLES



## LIST OF PHOTOS

# CHAPTER 1

# INTRODUCTION

## 1a. Background

The performance of rigid pavements has been for a long time a matter of concern for the U.S. Air Force. Many air force bases features such as runways, taxiways, and aprons have been constructed as rigid pavements and have structurally failed before the end of its design service live. These failures have been attributed primarily to increase in traffic loadings, changes in the geometrics of the main landing gear of new aircraft combined with the interaction of inadequate soil support, poor drainage, temperature gradients, use of marginal aggregates and inadequate load transfer at the joints. In addition, the rigid pavement design methodologies that have been developed in the past that have been used since recently, have certain limitations that were imposed by the state of the art at the particular stage of development.

The advances in computer technology during the last decade has permitted the application of techniques such as finite element method to analyze very complicated problems in a more rational manner. In rigid pavements in particular, a more comprehensive analysis of the state of stresses at pavement joints, cracks, and edges due to dynamic gear loadings, taking into account the non-linear behavior of soils can be more efficiently analyzed.

## 1b. Purpose

The purpose of this research study is to develop an analytical tool to analyze the performance of rigid pavements taking into account the non-linear behavior of soils using the finite element method. The end result is a computer program named Dynamic Non-Linear Pavement Analysis Program (DYNOPAV), a crack visualization and interpretation program (CRACK) and a user-friendly graphical input program of pavement features (GRINPAV).

## 1c. Scope

The research study will focus on the development of an analytical tool for analyzing the state of stresses due to dynamic gear loadings taking into account the non-linear behavior of soils. The analysis will concentrate on one plain slab without reinforcement, ties, or dowels and with a fixed length.

The report will include a description of the computer programs developed complemented with an input guide. Case study examples illustrating input procedures for the programs will also be included as well as outputs of the example problems.

# CHAPTER 2

# LITERATURE REVIEW

The literature review associated with the analytical study of concrete pavement behavior was concentrated on two major areas:

- non-linear analysis of stress and strains in soils and its applicability to pavement design and performance.
- state of the art in the analysis of concrete pavements with emphasis on the application of finite element formulation and modeling the dynamic effect of wheel loads configurations typically applied to pavement structures.

## 2.a Non-linear Analysis of Stress and Strain in Soils

The stress-strain behavior of any type of soil depends of a number of different factors including density, moisture, pore structure, drainage conditions, strain conditions, duration of loading, stress history, confining pressure, and shear stresses [5]. Non-linear analysis of stress and strains in fine-grained subgrades and granular materials have been used to model the behavior of concrete pavements subjected to different types of wheel loading configurations. A review of the literature related to non-linear analysis of stress and strain in soils is presented in the following paragraphs.

In its initial conception, the classical rigid pavement design and analysis methodologies assume that the subgrade is an elastic Winkler foundation represented by a bed of closely

spaced, independent, linear springs [35]. The stiffness of the springs, known as the modulus of subgrade reaction (k), relates the reactive pressure (p) to the deflection (w) at a given location in the subgrade. The value obtained is often termed the spring or the dense liquid constant. The equation is expressed as follows:

$$p = kw \tag{1}$$

The assumption relative to k is valid as long as the pavement slab is in complete contact with the supporting medium, (i.e. subgrade).

Several models are being developed to represent an elastic soil medium considering the non-linearity of the springs which more accurately approximate the stress softening behavior of fine-grained subgrade. The Ramberg-Osgood model [14] is specially suited for cyclic loading situations, were both loading and unloading curves are of interest.

The model for first loading is expressed in the following form:

$$\frac{w}{w_y} = \frac{p}{p_y} + a \left| \frac{p}{p_y} \right|^r \tag{2}$$

For reloading, the model is expressed as follows:

$$\frac{w-w_o}{2w_y} = \frac{p-p_o}{2p_y} + a \left| \frac{p-p_o}{2p_y} \right|^r \tag{3}$$

where:

$w_y$ = deflection at yielding, inch
$p_y$ = plate pressure at yielding, psi
$w_0$ = extreme deflection value of w for the cycle, inch
$p_0$ = extreme pressure value of p for the cycle, psi
a&r = constants determined experimentally

Butterfield and Georgiadis [2] developed an empirical equation to account for the non-linearity of the subgrade springs. The model shown in equation 4 takes into account the initial stiffness ($k_o$), a final stiffness ($k_f$) and a pressure axis intercept ($q_u$).

$$q = q_u \ (1-\exp \ (-(k_o-k_f) \ w/q_u)) + k_f w \tag{4}$$

The major drawback of the Winkler and non-linear springs model is the inability to adequately describe the behavior of the half space. In other words, it implies that no deflection response is feasible outside the loaded area, which in terms reflects that the deflection at any location is only a function of the pressure at that location. In reality, some deflection always occur outside the loaded area in terms of other models to describe elastic foundation response.

Filonenko-Borodich foundation [14] considers, in addition to the vertical springs, a stretched elastic membrane. The elastic membrane which is subjected to a constant tension field is connected to the top end of the springs to develop interaction among them. The amount of interaction is a direct function of the tension field. The formula used to relate subgrade stress and deflection is shown below:

$$q = kw - T\nabla^2 - w \tag{5}$$

where:

$q$ = subgrade stress, psi
$w$ = deflection, inches
$T$ = tension field
$\nabla^2$ = Laplace operator in x and y.

Pasternak [14] developed a two parameter model which takes into account the existance of shear interactions between the springs elements by tying the springs together at the top with a plate consisting of incompressible vertical elements that deform only by transverse shear. The relationship between subgrade stress and deflection is shown below:

$$q = kw - G\nabla^2 w \tag{6}$$

where:

q = subgrade stress, psi
w = deflection, inches
k = subgrade modulus, psi
G = plate shear modulus, psi

With the exception of the Ramberg-Osgood model all the previous models were developed for static loading conditions.

Repeated unconfined compression or triaxial testing procedures are used to evaluate the resilient moduli of fine-grained soils and granular materials [33]. Resilient moduli are stress dependent: fine-grained soils experience resilient modulus decreases with increasing stress, while granular materials stiffen with increasing stress levels.

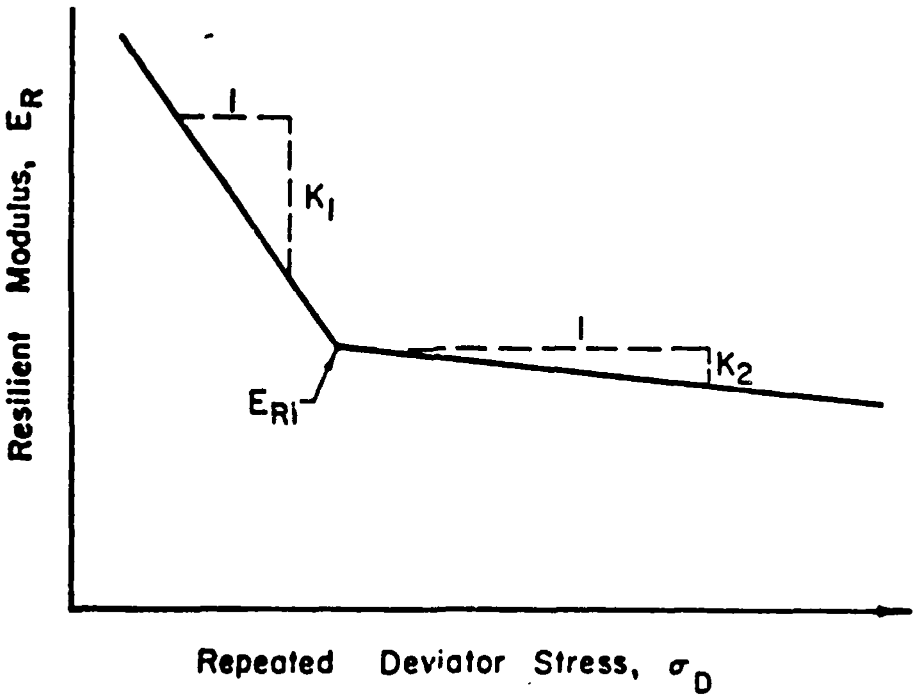
The general formula for measuring the resilient response if shown below:

$$E_R = \sigma_D/\epsilon_R \tag{7}$$

where:

$E_R$ = resilient modulus,psi
$\sigma_D$ = repeated deviator stress,psi
$\epsilon_R$ = recoverable axial strain

A graphical representation of the stress dependent resilient behavior of fine-grained soils is shown below. The value of the resilient modulus at the breakpoint in the bilineal curve, $E_{Ri}$, is a good indicator of a soils of the subgrade resilient behavior. The slope values, $K_1$ and $K_2$, display less variability and influence pavement structural response to smaller degree that $E_{Ri}$.




Repeated load triaxial testing is used to characterize the resilient behavior of granular materials and is a function of the applied stress tape. The mathematical relationship to determine the resilient modulus for granular materials is as follows:

$$E_R = K_1\theta^{K2} \tag{8}$$

where:

$E_R$ = resilient modululus for granular materials, psi
$K_1$ and $K_2$ = regression coefficients
$\theta$ = sum of principal stresses ($\sigma1 + \sigma2 + \sigma3$)

Duncan and Chang [5] presented a simplified, practical stress-strain relationship which takes into account the non-linearity, stress dependency, and inelasticity of soil behaviors.

Wang, Sargious, and Cheung [34] used a finite element method to determine the deflections and stresses in rigid pavement slabs with the subgrade acting as semi-infinite, elastic, homogeneous continuum. The slab is divided into individual, rectangular elements which are jointed at the spring final numbers of nodal points. The foundation is considered as consisting of a series of rectangular pressure areas whose centers coincide with and remain in contact with the nodal point of the slab. The pressure is assumed to be constant within each rectangle. He showed that the deflection for the foundation considered as an elastic continuum are much higher than those obtained by the Winkler assumption.

Duncan and Chang [5] analyzed the non-linear stress-strain relationship of soils using six parameters which includes the Mohr-Coulomb stress parameters (soil cohesion, c and friction angle, $\theta$) and four parameters that can be evaluated using the stress-strain curves of the same tests used to determine the values of c and $\theta$. The procedure to analyze the shear in loading is incremental in nature which essentially approximates the non-linear stress-strain relationship by a series of straight lines. The shortcoming of the iterative procedure is that it is very difficult to take into account non-zero initial stresses, which play an important role in many applications in soil mechanics. The principal advantage of the incremental procedure is that

initial stresses may be readily accounted for. It also has the advantage that, in the process of analyzing the effects of a given loading, stresses and strains are calculated for smaller loads as well. The accuracy of the incremental procedure may be improved if each load increment is analyzed more than once, in this way it is possible to improve the degree to which the linear increments approximates the non-linear soil behavior.

## 2.b. Concrete Pavement Analysis

The behavior of rigid pavements has been for a lcng time a matter of concern for the U.S. Air Force. In 1926, H.M. Westergaard published a report in the Highway Research Board Proceedings which contain mathematical equations to analyze stresses in concrete pavements [35]. The equations developed assumed that the slab is infinite in both x and y directions and the analysis of stresses at slab edges and corners had not been develop d. He further assumed the modulus of subgrade reaction, k, to be a constant at each point, independent of the deflections and to be the same at all points within the area which is under consideration.

In 1951 Pickett and Ray [20] developed influence charts for the solution of two cases of loading: (1) assuming that the subgrade acts as a dense liquid (i.e. conventional k), and (2) based upon the elastic solid case. The stresses could be determined for several wheel configurations. A computerized version of the Pickett and Ray influence charts has been developed and incorporated in the computer program H51ES [6].

This program, essentially, incorporates an analytical method for calculating the bending stress at the free edge of a loaded semi-infinite slab resting on a dense liquid or elastic solid foundation. The original computerized procedure was developed for the dense liquid subgrade and was later expanded to include the elastic solid idealization. The most significant limitations of the program are that the effects of thermal and moisture gradients as well as the lost of support beneath the slab are not considered. Base and subbase are not directly considered and only edge stresses can be calculated. Wheel configurations must be symmetrical about two perpendicular axles and jointing including slab sides and load transfer systems are not considered. The stresses are computed only for a semi-infinite plane PCC slab.

Both Westergaard analysis for liquid foundations [35] and Pickett's and Ray analysis for solid foundations [20] are based on the assumption that the slab and foundation are in full contact. This assumption is valid if there are no gaps between the slab and foundation, because the weight of the slab naturally imposes a large pre-compression on the foundation, which will keep the slab and foundation in full contact. However, this is not true when the slab is subjected to warping or pumping, which results in a separation between slab and foundation. Finite elements techniques are very useful for evaluating the effect of contact condition on the design and analysis of concrete pavements.

In 1966 the Portland Cement Association [21] developed a mechanistic procedure for design of rigid pavements based on Miner's hypothesis which considers the accumulative damage of the ratio of the stress associated with a particular wheel loading with respect to the flexural strength of the concrete.

In the last two decades, several models have been developed to analyze concrete pavement behavior using finite element techniques. ILLI-SLAB [28,29] developed by the University of Illinois, JSLAB [31] developed by the Portland Cement Association, WESLIQID [4] and WESLAYER [4] developed by the U.S. Corps of Engineers, and RISC [16] are examples of operational rigid pavement analysis models that have incorporated finite element formulations. A brief description of these models including their limitations are discussed in the following sections.

### 2.b.1 ILLI-SLAB

ILLI-SLAB was originally developed for structural analysis of one or two layer concrete pavements with or without mechanical load transfer systems at joints and cracks [28]. The finite element formulation is based on the classical theory of a medium-thick plate resting on a Winkler foundation. The model employs the 4-noded, 12 degrees of freedom plate bending element, and analyzes the subgrade as a uniform distributed subgrade through an equivalent mass formulation. The program uses a work equivalent load vector.

The current version of ILLI-SLAB incorporates partial slab-subgrade contact and thermal gradient modeling techniques.

In terms of limitations, ILLI-SLAB does not have the ability:

a. to consider all types of pavements or all factors that affect a pavement, specifically it considers a maximum of two slab layers in addition to the subgrade;

b. considers only a single slab, layer, and subgrade model when considering temperature gradients through the slabs and gaps between slab and subgrade;

c. does not consider the effects of drainability of the pavement section;

d. does not consider volume of vehicle traffic;

e. considers longitudinal and transverse joints and/or cracks with identical connections and load transfer mechanisms.

2.b.2 JSLAB

JSLAB is a finite element program that has very similar assumptions and derivations as compared to ILLI-SLAB. The subgrade is modeled as a Winkler type dense liquid, through an equivalent mass formulation as in ILLI-SLAB. JSLAB has identical capabilities as ILLI-SLAB with the exception of the partial contact with initial gap option [31]. In addition, JSLAB has the ability to consider nonuniformly spaced dowel bars across the longitudinal or transverse joints as well as considerations of noncircular load transfer devices.

In terms of limitations, JSLAB does not calculates the principal bending stresses as well as vertical stresses on the subgrade. Furthermore, only a one layer pavement system with a uniform thickness can be analyzed when a moisture gradient through the slab is considered. If the user specifies a vertical

slab displacement, it is not feasible to locate the applied loads at that particular node or over any element adjacent to that node. In terms of computer time, there is a significant amount of time required when the thermal gradient analysis is performed.

2.b.3 WESLIQID

The WESLIQID finite element computer program was developed for the analysis of concrete pavements subjected to both multiple wheel load arrangements as well as temperature gradients [4]. The subgrade is characterized as a dense liquid Winkler foundation in which the vertical forces and deformations are considered proportional to the corresponding vertical deflection. This technique can accomodate any number of rectangular shaped slabs arranged in any arbitrary pattern, connected by dowel bars or any other load transfer devices at the joints. The program can also handle cracks perpendicular or parallel to the joints.

In terms of limitations, the program is limited to a maximum of two pavement layers, in addition to the subgrade, and to a maximum of nine slabs and eleven joints of cracks with 200 nodes and 130 elements. Furthermore, temperature gradients are only considered for a slab with uniform thickness.

2.b.4 WESLAYER

The WESLAYER finite element program was developed to compute the state of stresses in a rigid pavement supported on an elastic solid or layered elastic foundation [4]. This program in terms of the method of solution and general input and output is very

similar to WESLIQID previously defined. In terms of capabilities, WESLAYER is essentially identical to WESLIQID with the exception that only two slabs uniformly thick may be modeled with one joint between them; this is due to the fact that large computer storage capacity is required by the elastic solid representation of the subgrade. The program uses as input and output essentially the same requirements as WESLIQID with the additional input of layered data, namely, modulus of elasticity and poisson ratio for the layered elastic representation of the subgrade.

In terms of limitations, WESLIQID is limited to a maximum of two slabs, one joint with 70 nodes and 60 elements, and limited to a maximum of 5 layers in the subgrade. Furthermore, temperature gradients may only be considered for uniformly thick slab configurations.

2.b.5 RISC

RISC is part of a mechanistic design procedure for rigid pavements and is based on the coupling of a finite element slab resting on a multilayer elastic solid foundation of up to 3 discrete layers [16]. The program considers up to 3 slabs in a row with or without shoulders as well as joint spacing, joint width, the effect of dowel bars and tie bars, load location, and thermal curling stresses.

In terms of limitations, the program requires a large amount of high speed computer time, essentially 30 to 50 minutes of CPU time for a single run, therefore, is quite expensive to use for

certain types of investigations. In terms of additional limitations, this program is limited to a standard dual wheel loading at a choice of three determined locations. All transverse joints must have identical load transfer mechanisms, and load transfer across longitudinal shoulder joint is not calculated. Unit weight and coefficient of thermal expansion of concrete slab as well as bending condition between layers are assumed in program and are not direct inputs. Flexural stresses in base and/or other support layers are not calculated neither subgrade stresses when more than one-layered pavements are modeled. Critical tension stress location in slabs (i.e. top or bottom) is not indicated, and only maximum displacements and stresses are output. Finally, the fatigue and faulting models presented are quoted in the literature as "questionable".

### 2.b.6 Other Finite Element Methodologies

Larralde and Chen [15] conducted a research study at Purdue University to develop a method for structural analysis of rigid pavements which considers the damage produced in the pavement structures by the repetitive actions of traffic loads. The damage is represented as a function of the reduction in concrete strength, deterioration in load transfer efficiency and pumping action.

Wang, Sargious, and Cheung [34] used the elastic solid methodology in the analysis of rigid pavements. The major difficulty they encountered in the use of solid foundations was in terms of the large computer storage required, because the

coefficient matrix for the large set of simultaneous equations is not banded, in contrast to the banded matrix when considering the subgrade as a dense liquid.

Chou [3] analyzed stress conditions in concrete pavements using the finite elements methods for slabs on liquid and elastic subgrades. In this study he found that the efficiency of load transfer accross a joint has an insignificant effect on the stresses and deflections in the slab when the load is placed at the center of the slab, but has a significant effect when the load is placed next to the joint. In addition, he showed that when the slab is in partial contact with the subgrade due to temperature warping, the assumption of the elastic response, as assumed by the Westergaard solution is not longer valid, even though the slab stresses are still within the elastic range.

Finally, he showed that the most critical condition in a rigid pavement occurs when there is no transverse joint or crack in the pavement, and also when the load is moving along its edge. Under the edge load, the presence of joints and cracks can reduce pavements stresses near the joints and the cracks, but increase the deflections in the same area. In a jointed pavement, the critical stress occurs when the load is half-way between the joints and the stress can have a magnitude close to that of a pavement with no transverse joint. Therefore, the presence of a joint does not reduce the maximum stress in a pavement. When the load is moving along the center of the pavement, the stresses are smaller, and are nearly independent of whether the load is at the center or next to the pavement joint.

Under both center and edge loads, maximum deflection occurs when the load is next to the transverse joint; corner deflection induced by the corner load is much greater. In terms of the theoretical deflection basin of the concrete slab, he demonstrated that is much flatter when the assumed subgrade is elastic than when it is liquid.

In 1986 the National Cooperative Highway Research Program awarded a research project to develop calibrated mechanistic structural analysis procedures for pavements using finite element methods. In 1989, the Federal Highway Administration [6] sponsored a research project to characterize and compare currently available rigid pavement analysis models and design methods and to develop new rigid pavement designs to be evaluated in full-scale experimental projects in an actual environment. The finite element formulations previously described in this chapter were analyzed in a great detail as part of this study.

The methodologies that have been used for analyzing concrete pavement behavior have had several drawbacks. The inability to simulate the dynamic effect of wheel loadings combined with the assumption of continuous support at the slab-subbase interface is by far the most critical drawback.

In the next chapter a description of the analytical methodology that was developed to model this drawback is presented.

# CHAPTER 3

# DESCRIPTION OF FINITE ELEMENT METHODOLOGY

## 3.a Finite Element Formulation

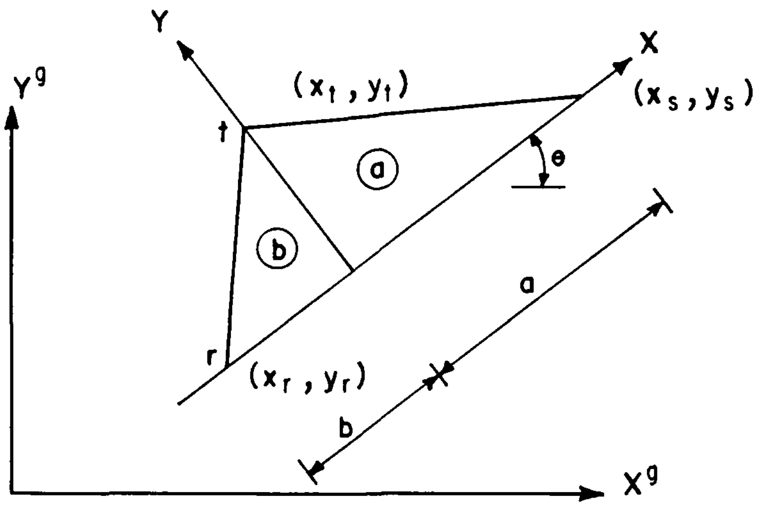
A triangular finite element with three nodes and three coordinates at each node was used as the basic element formulation. This element, developed by Rodríguez [25] in 1968, was selected because the computation of its stiffness matrix could be simplified reducing the amount of computing time required for the solution. As illustrated in Figure 1, there is a displacement function for each subelement. Originally the displacement formulation had a total of thirty-two constants which were reduced to fifteen by imposing compatibility. The element exhibits lack of compatibility in some specific cases, but even so, it converges and has been proved to give good results.

The general element stiffness matrix is given by:

$$Ke = t^3/12\ [C^{-1}]^T \{ \int_{A_A} [Ba]^T\ [D][Ba]dA + \int_{A_B} [Bb]^T\ [D][Bb]dA \} [C^{-1}] \qquad (1)$$

The element stiffness matrix is rotated to global coordinates and added to the total pavement stiffness matrix.

In Appendix A, the matrices [C], [Ba] and [Bb] are given. The material rigidity matrix is discussed and presented in section 3.g where the concrete behavior representation is explained.




$$W_a = \alpha_1 + \alpha_2 X + \alpha_3 Y + \alpha_4 X^2 + \alpha_6 XY + \alpha_7 Y^2 + \alpha_8 (mX^3 + XY^2) + \alpha_9 (mX^3 + Y^3)$$

$$W_b = \alpha_1 + \alpha_2 X + \alpha_3 Y + \alpha_5 X^2 + \alpha_6 XY + \alpha_7 Y^2 + \alpha_8 (m'X^3 + XY^2) + \alpha_9 (n'X^3 + Y^3)$$

where:

$$m = [2 - (h/a)^2]/3 \qquad n = -h/a$$

$$m' = [2 - (h/b)^2]/3 \qquad n' = h/b$$

Figure 1 - Element Displacement Expansion.

### 3.b Matrix Condensation

For the dynamic analysis it is convenient to condense the stiffness matrix to eliminate all rotational coordinates of the general dynamic solution. To simplify the matrix condensation, rotational coordinates are enumerated consecutively after the displacement and vehicle coordinates. This condensation is performed using the following matrix relations:

$$\{F_{TOT}\} = \{K_{TOT}\}\ \{U_{TOT}\} \tag{2}$$

$$\{F_V/F_R\} = \begin{bmatrix} K_{VV} & K_{VR} \\ K_{RV} & K_{RR} \end{bmatrix} \begin{Bmatrix} U_V \\ U_R \end{Bmatrix} \tag{3}$$

where subscript V represents vertical plus vehicle coordinates and subscript R represents rotational coordinates.

$$\{F_V\} = [K_{VV}]\ \{U_V\} + [K_{VR}]\ \{U_R\} \tag{4}$$

$$\{F_R\} = [K_{RV}]\ \{U_V\} + [K_{RR}]\ \{U_R\} \tag{5}$$

From equation five we can solve for $\{U_R\}$

$$\{U_R\} = [K_{RR}]^{-1}\ \ \{F_R\} - K_{RV}\ \{U_V\} \tag{6}$$

Substituting in four, equation six and simplifying we have:

$$\{F_V\} - [K_{RR}]^{-1}\ \{F_R\} = [[K_{VV}] - [K_{VR}][U_{RR}]^{-1}[K_{RV}]]\{U_V\} \tag{7}$$

$$[K_V] = [K_{VV}] - [K_{VR}]\ [K_{RR}]^{-1}\ [K_{RV}] \tag{8}$$

$$\{F_V\}_{Red} = \{F_V\} - [K_{RR}]^{-1}\ \{F_R\} \tag{9}$$

The reduced stiffness matrix (8) and the load vector (9) are used in the step by step dynamic analysis. Formula six is used to compute the rotational displacement at each step to be able to compute the flexural moment and stresses at each element.

### 3.c Vehicle Representation

The vehicle representation is done by assuming a rigid body supported in n axles or gears. Each axle or gear can have two pavement contact points or tires. There are three coordinates of motion at the rigid body, two vertical coordinates at each axle or gear and two vertical coordinates at the contact points between the tires and the pavement. A graphical representation of the vehicle is shown in Figure 2 and the corresponding stiffness matrix is included in Appendix A.

The percent of mass concentrated at the main body is given as input and the center of gravity of the vehicle mass is computed by statics using the magnitude of the axle or gear loads.

### 3.d General Dynamic Formulation

The general dynamic formulation is given by the following equations:

$$[M_V]\ \{\ddot{y}_V\} + [K_V]\ \{Y_V\} + [K_T]\ \{\{Y_V\} - \{Y_0\}\} = \{F_V\} \tag{10}$$

$$[M_V]\ \{\ddot{y}_V\} + [[K_V] + [K_T]]\ \{y_V\} = \{F_V\} + [K_T]\ \{y_o\} \tag{11}$$

In this equation $[M_V]$ corresponds to the mass matrix, $[K_V]$ to the global reduced stiffness matrix, $[K_T]$ to the vehicle stiffness matrix, $\{F_V\}$ to the reduce force vector, $\{\ddot{y}_V\}$ to the displacement acceleration, $\{y_o\}$ to the roughness vector and $\{y_V\}$ to the vertical displacement vector for pavement and vehicle coordinates.

The force vector is reduced in two components; the static initial force due to temperature and pavement slab weight and the

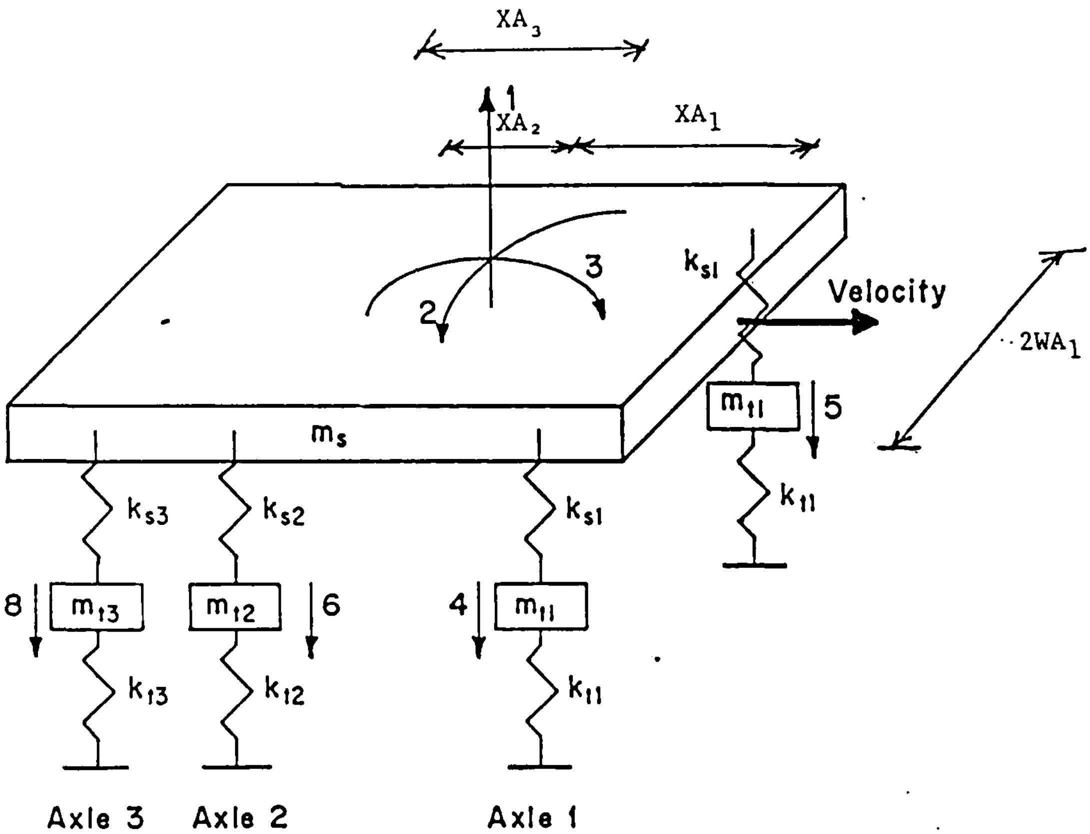



Figure 2 - Vehicle Representation.

dynamic force induced by the vehicle as its moves along the pavement.

At each step the location of each axle or gear contact point is determined. The vehicle stiffness matrix and the vehicle forces are added to the total pavement stiffness matrix and total force vectors at the coordinates in which the axles or gears are in contact. In most of the cases the axle or gear tire location does not coincide exactly with the coordinate location, thus a linear interpolation is made between the four corresponding coordinates. (See Figure 3).

### 3.e Numerical Integration

At each interval the dynamic equation given in section 3.d is solved using lumped-impulse numerical integration. First, the acceleration is computed with the displacement of the previous step using the dynamic equation that follows:

$$\{\ddot{y}_V\}^{(s)} = (\{F_V\}^{(s)} + [K_T]\,[Y_o] -$$
$$([K_V] + [K_T]^{(s)})\{Y_V\}^{s}) \begin{bmatrix} 1/M_1 & 0 & 0 & 0\ldots \\ 0 & 1/M_2 & 0 & 0\ldots \\ 0 & 0 & 1/m_3 & 0\ldots \end{bmatrix} \qquad (12)$$

The displacements for the following steps are then computed using the following recurrence formula.

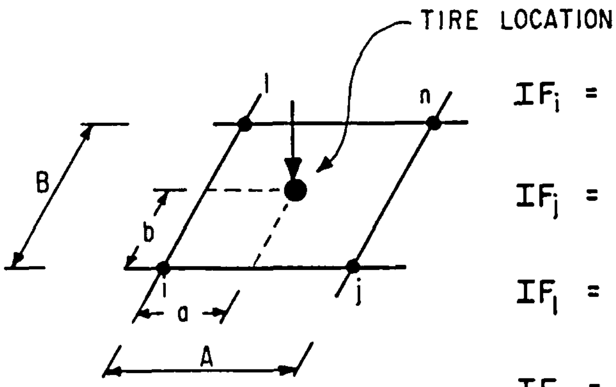
$$\{y_V\}^{(s+1)} = 2\{y_V\}^{(s)} - \{y_V\}^{(s-1)} + \{\ddot{y}_V\}^{(s)}\,(\Delta t)^2 \qquad (13)$$

For the first step a special procedure is required.

The acceleration is assumed to vary linearly up to the first step and the displacements are given by the following formulas:

$$\{y\}^{(1)} = 1/6\,\{\ddot{y}\}^{(1)}\,(\Delta t)^2 \qquad (14)$$

or $$\{\ddot{y}\}^{(1)} = 6/\Delta t^2\,\{y\}^{(1)} \qquad (15)$$




$$IF_i = \frac{(A-a)(B-b)}{A \times B}$$

$$IF_j = \frac{a(B-b)}{A \times B}$$

$$IF_l = \frac{(A-a)b}{A \times B}$$

$$IF_n = \frac{ab}{A \times B}$$

Figure 3 - Interpolation Factor for Axle Contribution.

If the expression for the acceleration is substituted in the general dynamic equation (11), then it can be solved directly for the first step displacement. After obtaining the first step displacement, the first step acceleration is obtained and the normal numerical integration procedure is performed in the subsequent steps.

### 3.f **Vehicle Approach**

Two vehicle approaches have been implemented. The first corresponds to the case in which the vehicle enters the slab coming from a previous slab.

In this case, three hundred steps of the vehicle moving over a rigid pavement at the input velocity and corresponding time interval are analysed prior to the vehicle entering the pavement. The vehicle acceleration and displacement coordinates at the end of the approach procedure are the initial conditions for the step by step dynamic analysis.

The second approach corresponds to the case in which the front vehicle axle makes a sudden contact with the pavement at a given distance from the starting edge. In this case, the initial condition is the sudden application of all the axles or gear loads within the pavement.

### 3.g Concrete Behavior (Crack Development Procedure and Stiffness Variation)

The general concrete stiffness matrix for the plate flexure formula is defined as recommended by Darwin and Pecknold:

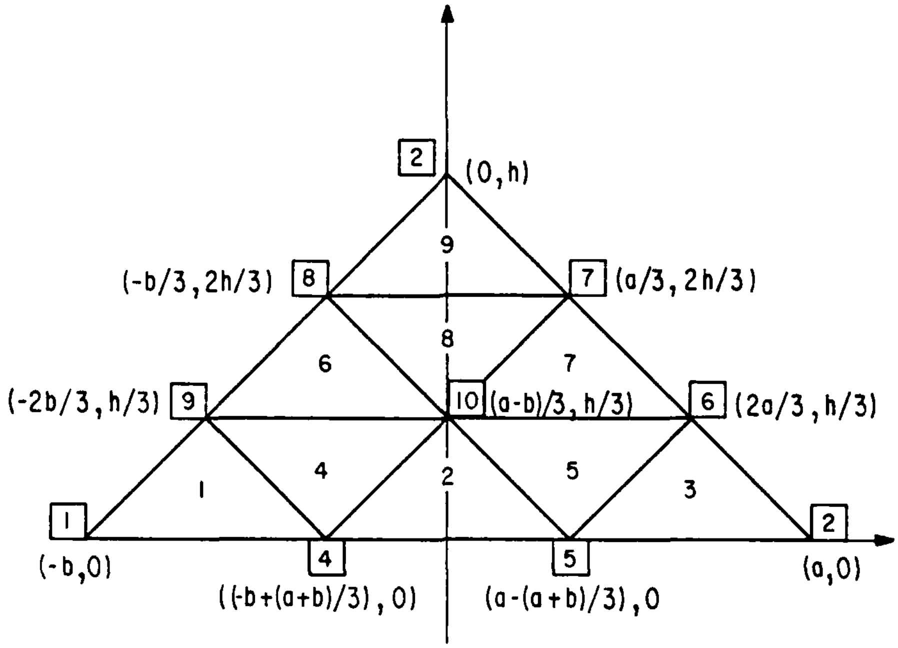
$$[D] = \frac{1}{1 - v_2} \begin{bmatrix} E_1 & v\sqrt{E_1\ E_2} & 0 \\ v\sqrt{E_1\ E_2} & E_2 & 0 \\ 0 & 0 & 1/4(E_1+E_2-2v\sqrt{E_1E_2}) \end{bmatrix} \qquad (16)$$

The behavior of the concrete in tension and compression up to cracking is considered essentially linear and the uncracked rigidity matrix is given by:

$$[D] = \frac{1}{1 - v^2} \begin{bmatrix} E_T & vE_T & 0 \\ vE_T & E_T & 0 \\ 0 & 0 & \frac{(1-v)}{2}\ E_T \end{bmatrix} \qquad (17)$$

In order to determine and consider the crack formation, the principal stresses were computed for each step in nine locations within each triangular element as shown in Figure 4. A crack index was stored and updated at each step for each of the nine points of each element depending of the stress conditions at the given point. A vector with the direction of the crack with respect to local axis is also stored and modified at each step for each point within each element. At each of the nine points within an element the material rigidity matrix is modified to consider the formation of cracks in a given direction or in both directions.

If a crack is active at a given interval in a given direction the modulus of elasticity in that direction is set to zero and the rigidity matrix is rotated to the local element




| TRIANGLE | COORDINATES IN X | COORDINATES IN Y |
|---|---|---|
| 1 | 1/9 (a-7b) | 1/9h |
| 2 | 4/9 (a-b) | 1/9h |
| 3 | 1/9 (7a-b) | 1/9h |
| 4 | 1/9 (2a-5b) | 2/9h |
| 5 | 1/9 (5a-2b) | 2/9h |
| 6 | 1/9 (a-4b) | 4/9h |
| 7 | 1/9 (4a-b) | 4/9h |
| 8 | 2/9 (a-b) | 5/9h |
| 9 | 1/9 (a-b) | 7/9h |

Figure 4 - Concrete Stress Computation Location.

axis. All rotated rigidity matrices for each point within an element are added and the average for each element is obtained. If a change in crack condition is observed within an element at a given step, the difference between the crack rigidity matrix and the uncracked rigidity matrix is used to compute the reduction in contribution of the given element to the total stiffness matrix.

The element stiffness reductions are subtracted to the original uncracked pavement total stiffness matrix.

When any of the elements change its state of cracking in a given step it is necessary to read from discs the original total uncracked stiffness, modify it with the changes in element stiffness and then condense it.

The procedure used to condense the stiffness matrix consumes a significant amount of computing time and should be further studied to optimize it. Element stiffness matrix condensation against total stiffness matrix condensation should be considered as an alternative.

### 3.h **Soil Nonlinear Behavior**

The soil structure interaction procedure is an important factor in the behavior of concrete pavements. In this research project, after analyzing the different models described in the literature search, it was decided to use the dense liquid concept because it facilitates the nonlinear behavior implementation.

The nonlinear soil behavior was included in the implementation for a one layer subbase using the modulus of subgrade reaction as well as the resilient modulus relationship given by:

$$E_t = K_1 \, \theta^{K_2} \tag{18}$$

where:

$E_t$ = tangent modulus of subgrade reaction, psi
$K_1$ = soil constant which varies from 3,000 to 8,000 psi
$K_2$ = soil constant which varies from 0.5 to 0.7
$\theta$ = sum of principal stresses or stress invariant, psi

Typical values of $K_1$ and $K_2$ for unbound base and subbase materials for different moisture conditions are shown in Table 1.

TABLE 1

TYPICAL VALUES FOR $K_1$ AND $K_2$ FOR UNBOUND BASE AND SUBBASE MATERIALS [1]

| (a) Base | | |
|---|---|---|
| Moisture Condition | $K_1$* | $K_2$* |
| Dry | 6,000 - 10,000 | 0.5 - 0.7 |
| Damp | 4,000 - 6,000 | 0.5 - 0.7 |
| Wet | 2,000 - 4,000 | 0.5 - 0.7 |
| **(b) Subbase** | | |
| Dry | 6,000 - 8,000 | 0.4 - 0.6 |
| Damp | 4,000 - 6,000 | 0.4 - 0.6 |
| Wet | 1,500 - 4,000 | 0.4 - 0.6 |

* Ranges in $K_1$ and $K_2$ are a function of the material quality.

As shown in Figure 5, the stresses for step n + 1 are obtained at under each joint at the user's specified layer depth (h). The stress computations are done using the following formulas:

$$\sigma_x^{n+1} = \sum_{L=1}^{K} R_i \, C_{xi} \, \Delta A / A_i \tag{19}$$

$$= \sum_{i=1}^{K} K_i^n \, \delta_i^{n+1} \, C_{xi} \, \Delta A / A_i$$

$$\sigma_y^{n+1} = \sum_{L=1}^{K} K_i^n \, \delta_i^{n+1} \, C_{yi} \, \Delta A / A_i \tag{20}$$

$$\sigma_z^{n+1} = \sum_{L=1}^{K} K_i^n \, \delta_i^{n+1} \, C_{zi} \, \Delta A / A_i \tag{21}$$

where:

$K_i^n$ = spring constant at step n (i.e. modulus of subgrade reaction multiplied by area $A_i$)

$\delta_i^{n+1}$ = vertical displacement at step n + 1

$A_i$ = contribution area for joint i (see Figure 5)

$C_{xi}$, $C_{yi}$, $C_{zi}$ = influence coefficient to compute stresses at elevation z using Boussinesq formula

$\Delta A$ = differential area used in the numerical integration to compute the influence coefficient (see Figure 6)

K = counter which is set to 4 for corner joints, 8 for edge joints, and 16 for middle joints

The contribution on the soil stresses of the equivalent forces at all adjacent points is considered. Four adjacent joints are considered for a corner joint, six for an edge joint and nine for a middle joint.

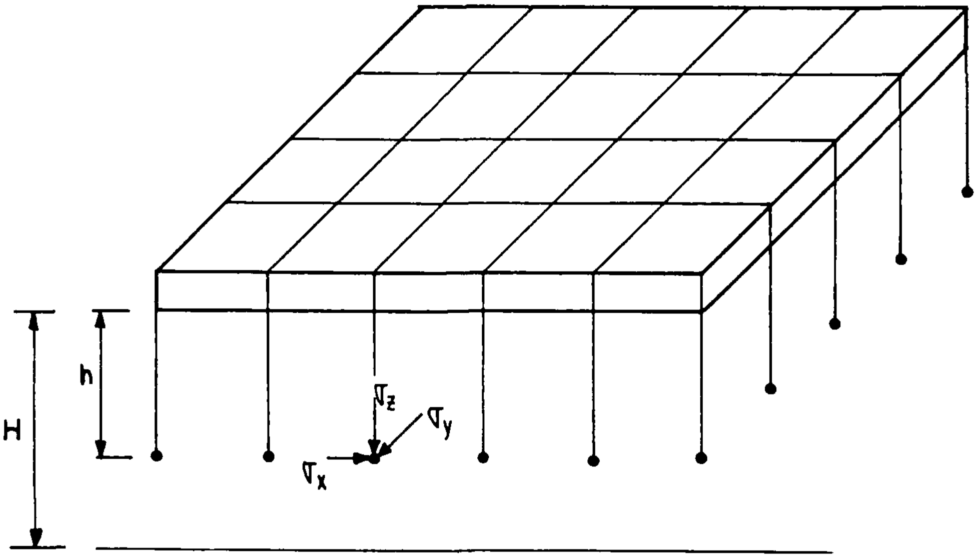



Figure 5 - Soil Element Stress Computation Location.

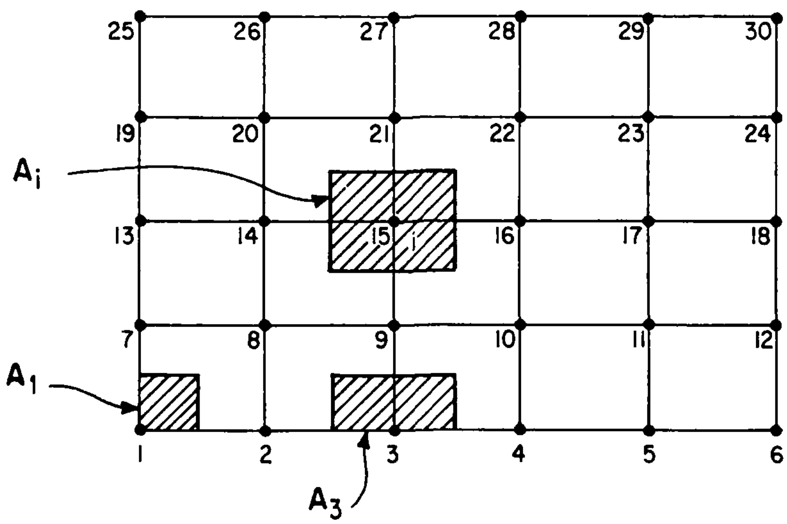


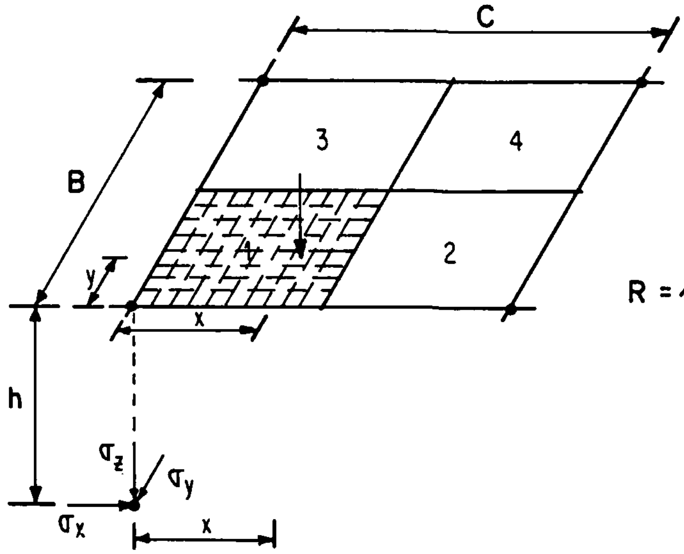

Figure 6 - Joints Contribution Area.

To determine the influence coefficient, Boussinesq equations were used to compute stresses at a given depth due to concentrated forces. To determine a uniform distributed pressure, the equivalent spring forces at each joint for each step were divided by the joint contribution area. This pressure, multiplied by the differential area used in the numerical integration, represented a small equivalent concentrated force at each differential area. (See Figure 7). If at a given step at a given joint a tension force is found, the soil stiffness is assumed to be zero for the next step.

Four independent coefficients were computed for each stress direction. Each coefficient corresponded to the influence of the pressure at four different quadrants. Each quadrant is divided as a 10 by 10 mesh. An integration is carried out to obtain each quadrant coefficient. In Figure 7, the corresponding formulas and geometry are shown.

After the influence coefficients are computed, the stresses are obtained by adding the influence of all the quadrants contributing for a given joint as defined by the formulas 19 to 21. Four quadrants are included for a corner joint, eight cuadrants for an edge joint and sixteen for a middle joint.

Once the horizontal and vertical stresses are known, the principal stresses are computed applying the Mohr-Coulomb theory to determine if there had been any failure at the subbase.




$$P_i = \left(\frac{K_i^n \, \delta_i^n}{A_i}\right) \Delta A$$

$$R = \sqrt[2]{x^2 + y^2 + z^2}$$

$$C_{xk} = \frac{1}{2\pi} \sum_{L=1}^{100} \frac{1}{r^3} \left[ (1 - 2\mu) \frac{r^2(h + r) - x^2 (h + 2r)}{(h + r)^2} - \right.$$

$$\left. - \frac{h(r^2 - 3x^2)}{r^2} + 2\mu h \right]$$

$$C_{yk} = \frac{1}{2\pi} \sum_{L=1}^{100} \frac{1}{r^3} \left[ (1 - 2\mu) \frac{r^2(h + r) - y^2 (h + 2r)}{(h + r)^2} - \right.$$

$$\left. - \frac{h(r^2 - 3y^2)}{r^2} + 2\mu h \right]$$

$$C_{zk} = \frac{3}{2\pi} \sum_{L=1}^{100} \frac{h^3}{r^5}$$

Figure 7 - Influence Coefficient.

The intermediate value of the three principal stresses is identified and used to determine the limited value for minimum and maximum principal stresses using the following formulas:

$$(\sigma_1)_{max} = \sigma_i \tan^2 (45 + \phi/2) + 2c \tan (45 + \phi/2) \quad (22)$$

$$(\sigma_3)_{min} = \sigma_i \tan^2 (45 - \phi/2) + 2c \tan (45 - \phi/2) \quad (23)$$

where:

$\sigma_i$ = principal stress intermediate values, psi

$\phi$ = angle of friction

c = soil cohesion, psi

Actual principal stresses are compared to minimum and maximum principal stresses and modified as described in the flow chart in Figure 8.

Once the modified principal stress is known the soil invariant, the soil modulus of subgrade reaction and the equivalent spring stiffness are computed.

### 3.i **Pavement Roughness**

The pavement roughness parameters are generated at random with a special purpose program. This program generates a file with a two column matrix, one column for each of the two tracks assumed. This random generated matrix is then smoothed out linearly by interpolating fifty intermediate points. A maximum amplitude of a half inch is assumed in the roughness generation routine but the user could modify it by giving another amplitude. The file unit is feet. A typical track roughness generated by this procedure is shown in Figure 9.

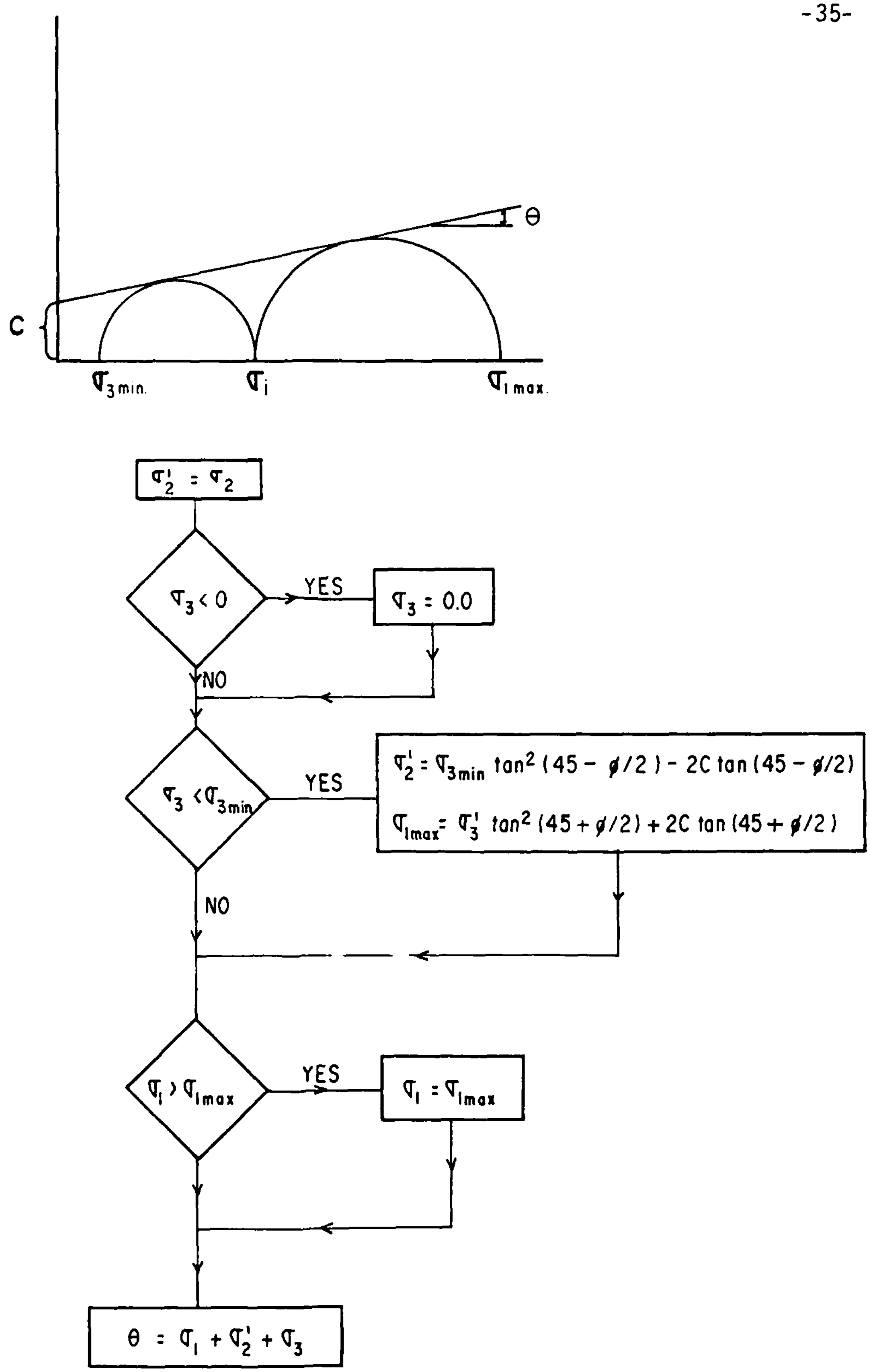



Figure 8 - Soil Failure Check Flow Chart.

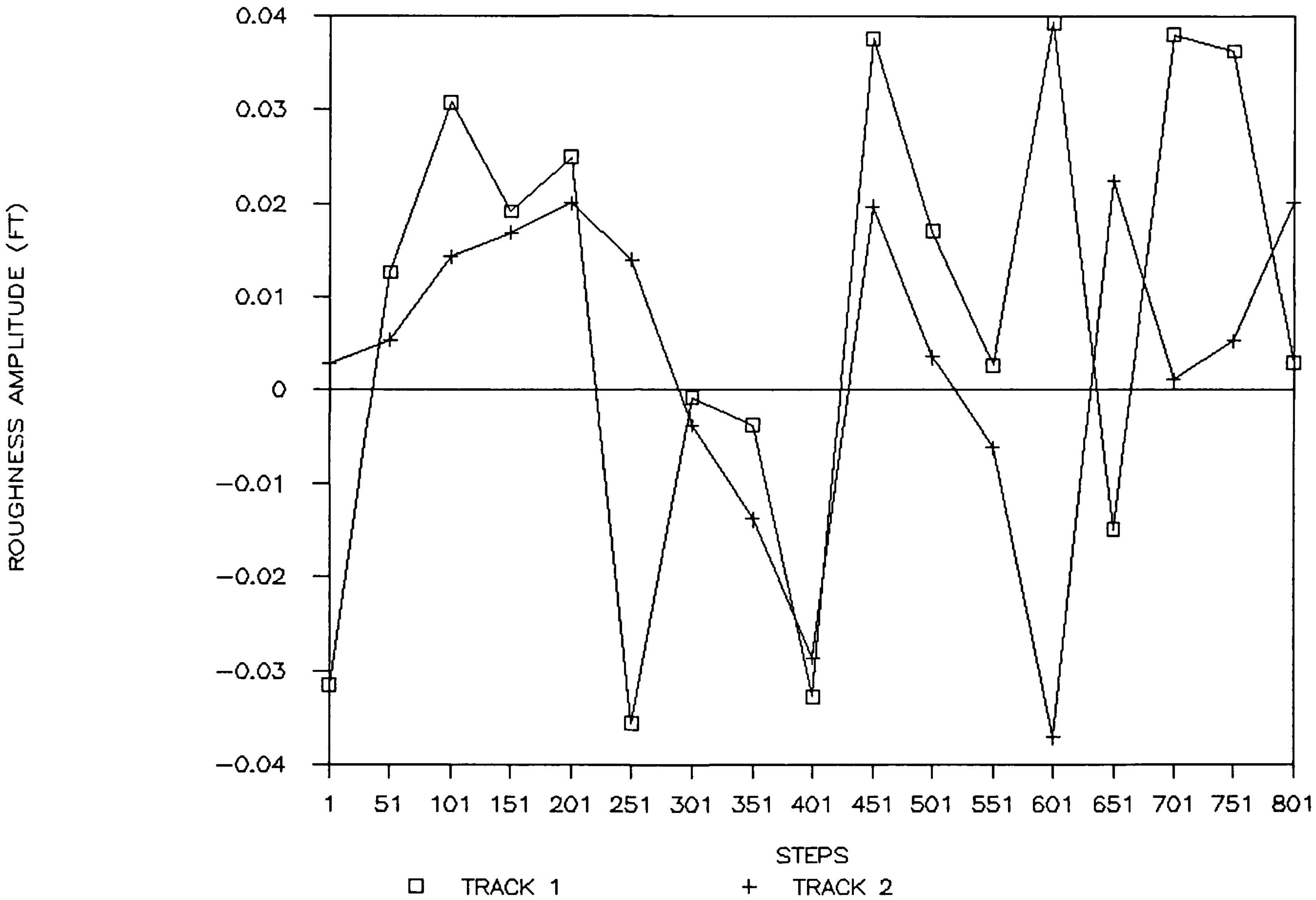



Figure 9. Roughness Amplitude

In the procedure used it is assumed that the distance between each roughness coefficient corresponds to the distance traveled by the vehicle in each step. The relative position of an axle or gear in each track is determined to read the corresponding roughness magnitude. Therefore, different axles and gears will observe the same magnitude of roughness at a given position in the pavement.

The file in which the smoothed-out roughness is stored is named RUG.DAT.

# CHAPTER 4

# DESCRIPTION OF PROGRAMS

## 4.a Dynamic Nonlinear Pavement Analysis Program (DYNOPAV)

### 4.a.1 Description

The main program developed as part of this project is called DYNOPAV. It is the one in which the methodology for nonlinear dynamic analysis of concrete pavements has been implemented. This program consists of seven fortran programs (name.for) linked together. The functions of these programs are described below:

a. AF1001.FOR - This is the main program. It reads and writes data, forms linear stiffness matrix and solves for temperature and dead load.

b. AF2001.FOR - Consists of five subroutines that perform general geometry computation.

c. AF3001.FOR - It is composed of eight subroutines that compute the element stiffness matrix.

d. AF4001.FOR - This part is composed of six subroutines that assemble and condense the total global stiffness, adds vehicle contribution to the stiffness matrix, assembles the force vector and obtains the static solution.

e. AF6001.FOR - Consists of nine subroutines that perform computations for moment resultant and stress.

f. AF7001.FOR - It is the subroutine that performs the procedure of the nonlinear dynamic analysis.

g. AF8001.FOR - It consists of four subroutines that will perform the concrete and soil nonlinear computations and procedure.

In Figure 10, a general flow chart for the DYNOPAV program is given.

**DYNOPAV FLOW CHART**

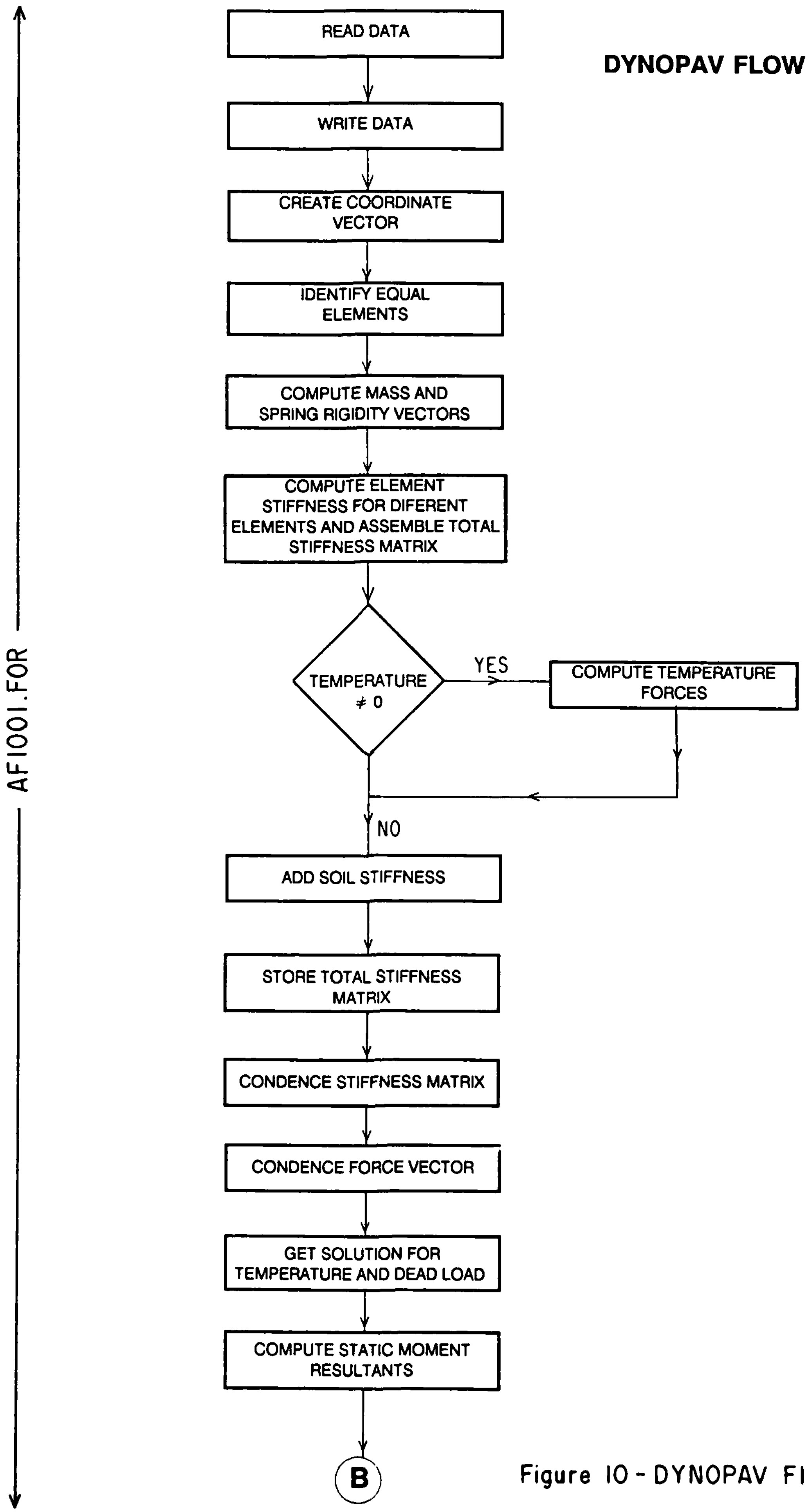
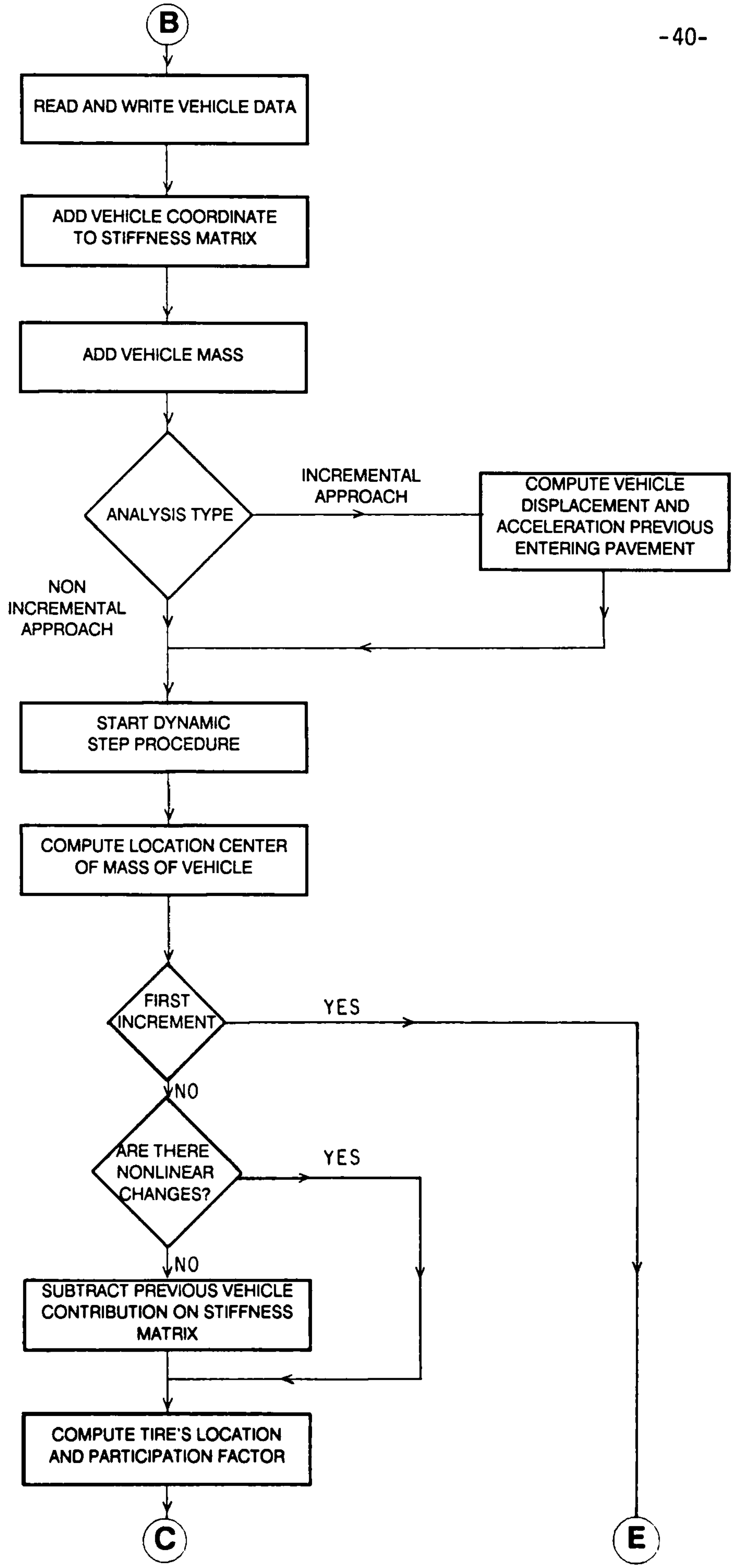
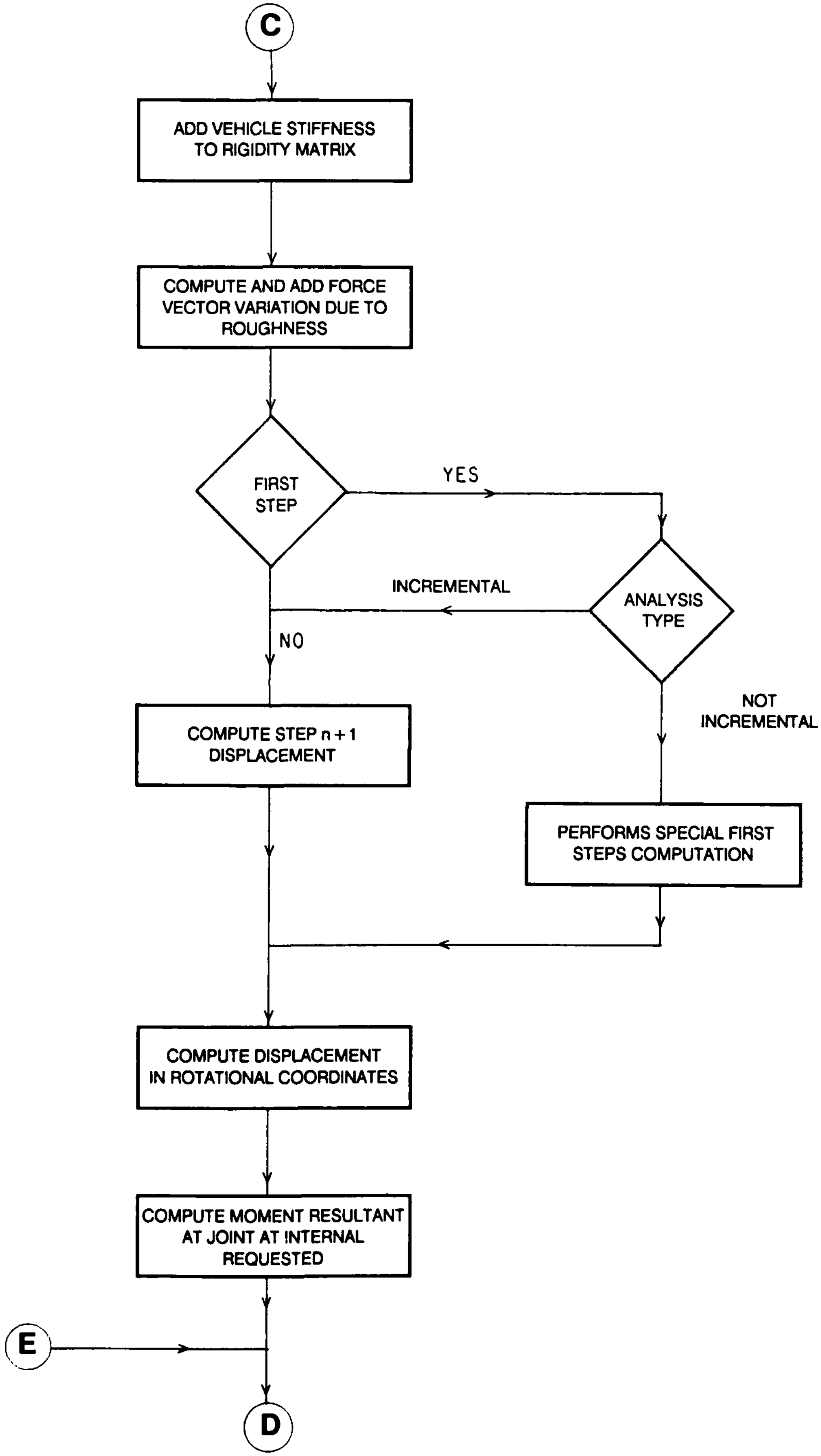
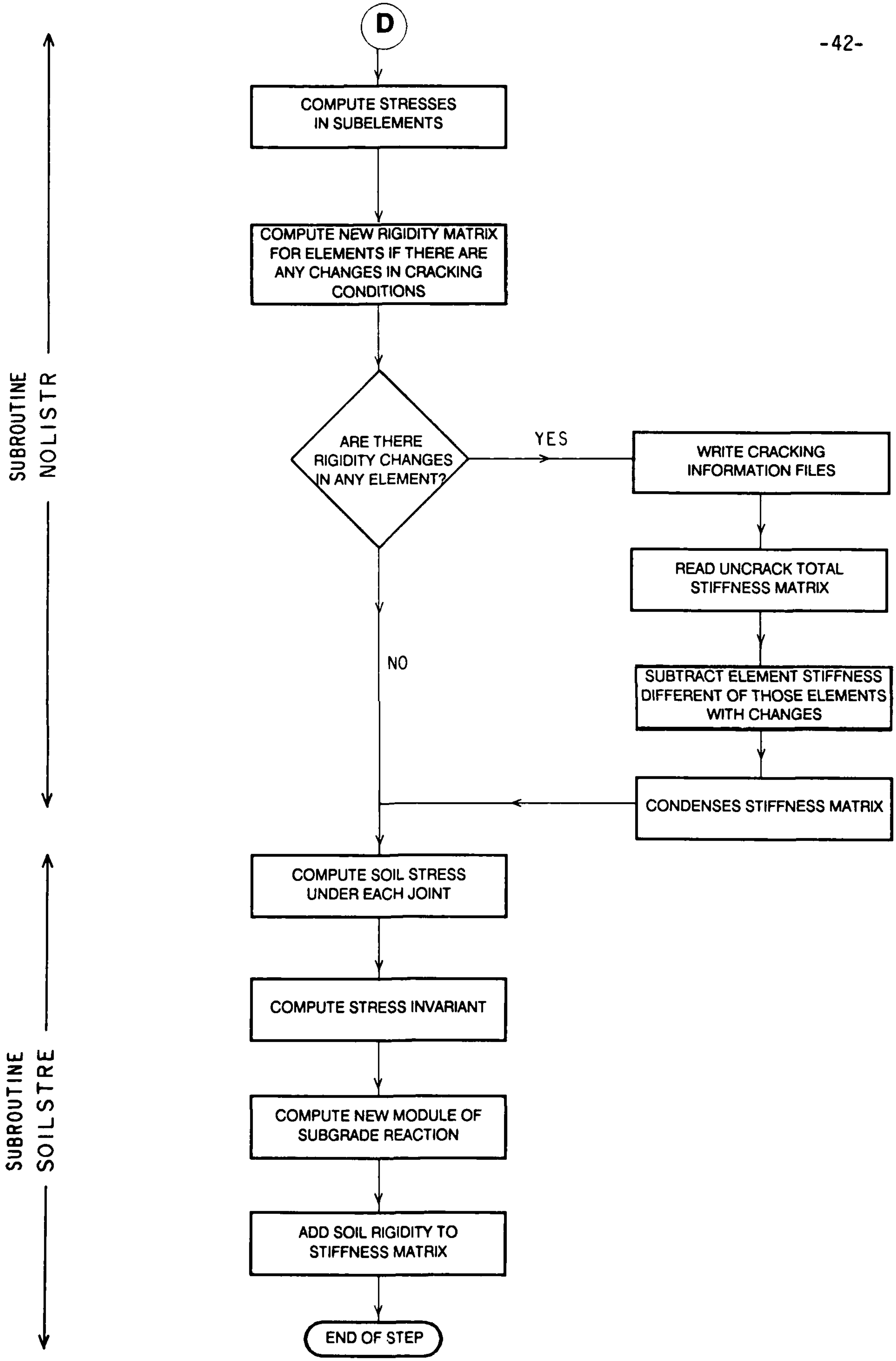



Figure 10 - DYNOPAV Flow Chart.


B
READ AND WRITE VEHICLE DATA
ADD VEHICLE COORDINATE TO STIFFNESS MATRIX
ADD VEHICLE MASS
ANALYSIS TYPE
INCREMENTAL APPROACH
COMPUTE VEHICLE DISPLACEMENT AND ACCELERATION PREVIOUS ENTERING PAVEMENT
NON INCREMENTAL APPROACH
START DYNAMIC STEP PROCEDURE
COMPUTE LOCATION CENTER OF MASS OF VEHICLE
FIRST INCREMENT
YES
NO
ARE THERE NONLINEAR CHANGES?
YES
NO
SUBTRACT PREVIOUS VEHICLE CONTRIBUTION ON STIFFNESS MATRIX
COMPUTE TIRE'S LOCATION AND PARTICIPATION FACTOR
C
E


C
ADD VEHICLE STIFFNESS TO RIGIDITY MATRIX
COMPUTE AND ADD FORCE VECTOR VARIATION DUE TO ROUGHNESS
FIRST STEP
YES
ANALYSIS TYPE
INCREMENTAL
NO
NOT INCREMENTAL
COMPUTE STEP n + 1 DISPLACEMENT
PERFORMS SPECIAL FIRST STEPS COMPUTATION
COMPUTE DISPLACEMENT IN ROTATIONAL COORDINATES
COMPUTE MOMENT RESULTANT AT JOINT AT INTERNAL REQUESTED
E
D


D
COMPUTE STRESSES IN SUBELEMENTS
COMPUTE NEW RIGIDITY MATRIX FOR ELEMENTS IF THERE ARE ANY CHANGES IN CRACKING CONDITIONS
ARE THERE RIGIDITY CHANGES IN ANY ELEMENT?
YES
WRITE CRACKING INFORMATION FILES
READ UNCRACK TOTAL STIFFNESS MATRIX
SUBTRACT ELEMENT STIFFNESS DIFFERENT OF THOSE ELEMENTS WITH CHANGES
CONDENSES STIFFNESS MATRIX
NO
COMPUTE SOIL STRESS UNDER EACH JOINT
COMPUTE STRESS INVARIANT
COMPUTE NEW MODULE OF SUBGRADE REACTION
ADD SOIL RIGIDITY TO STIFFNESS MATRIX
END OF STEP
SUBROUTINE NOLISTR
SUBROUTINE SOILSTRE

### 4.a.2 Input Data

All the necessary ASCI files to perform the nonlinear dynamic analysis can be obtained using the Graphical Input Pavement Program (GRINPAV) described later in this report. It is also possible to prepare the necessary data files using a word processor.

The DYNOPAV program requires four ASCI files. The first file is a general data file with the name of the problem to be solved; the extension .ANA contains the following information in strict order:

a. Name of the problem - maximum of eight characters

b. Title of the problem - general description, up to 80 characters

c. Number of joints, number of elements, and number of axles or gears

d. Slab thickness, (ft)

e. Concrete modulus of elasticity (ksf)

f. Concrete Poisson Ratio

g. Temperature gradient (°F), and concrete thermal expansion coefficient, (°F)

h. Concrete cracking stress, (ksf)

i. Number of total intervals*, stress output interval, displacement output intervals, soil output interval, sum of soil output intervals

j. Rotational mass in x ($k - sec^2$), rotational mass in y ($k - sec^2$), and mass factor

k. For each axle or gear, the following information is required (see Figure 11): distance of first axle or gear to vehicle centroid (ft), distance between contact points (ft), axle or gear load ** (k), tire stiffness (k/ft), and vehicle stiffness (k/ft)

l. Time interval for each step (secs), entrance distance in y (ft), and velocity (ft/sec)

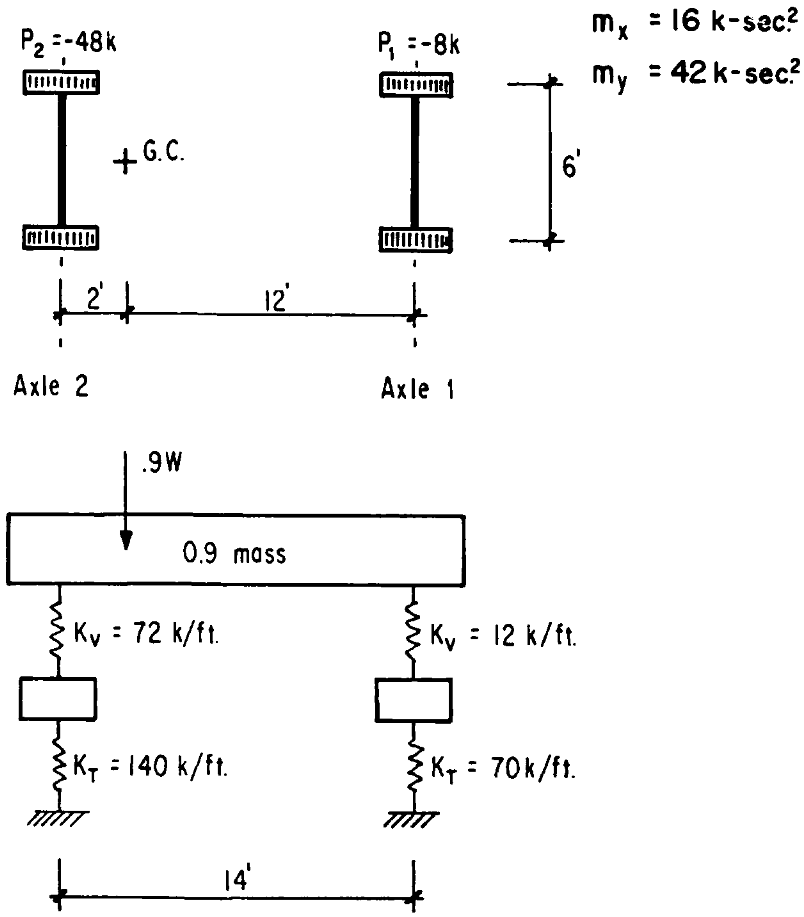



Figure 11 - Vehicle Parameter Used in Example Problems.

m. Soil coefficient $K_1$, soil coefficient $K_2$, soil poisson, depth of subbase (ft), stress computation depth (ft), soil friction angle (degrees), and soil cohesion (ksi).

n. Analysis type; 3 for sudden and 4 for incremental

Remarks

* If 0 is given, the program will compute the total number of steps required for the vehicle to cross the total slab length.

** Should be negative.

In Table 2 a typical input file is shown. In addition to these files, four additional files are needed. A joint coordinates file that includes the coordinates, in feet, of the joints is required at the beginning and at the end of each row. The program will equally divide the distance between joints automatically. In the transverse direction, the coordinates given at the start and end of each row should also be equally spaced. This requirement was imposed to simplify and reduce the nonlinear dynamic computations. This array should be called problem name.COO. No format is required and the joint number and corresponding x and y coordinates need to be separated by blanks or a comma.

An array called problem name.INC with the triangular element incidences should also be input by the user. The program automatically generates the incidence for elements between the first and last row. No format is required, therefore, the element number as well as the, first, second and last joint numbers should be separated by blanks or comma. Joints should be given in counter-clockwise order.

```
EXAM1-1
EXAMPLE 1SMOOTH PAVEMENT, VEL=50,K1=4000.,K2=.6,EC=518400.KSF,FC=144KSF
   49      72       2    # OF JOINT,# OF ELEM,# OF AXLE
   0.100000E+01    PAVEMENT THICKNESS
   0.518400E+06    CONCRETE TANGENT MODULUS
   0.160000E+00
                                                  POISSON RATIO
      0.00      0.500000E-04   TEMPERATURE GRADIENT AND EXPANSION COEFFICIENT
   0.144000E+03    CONCRETE CRACKING STRESS (K/FT^2)
   0.000000E+00
                                             ROUGHNESS AMPLITUD
 200      1     100      1     100      1     100      1      20   PRINT PARAMETERS
   16.0     42.0      0.9
   12.0      6.0     -8.0     70.0     12.0
   -2.0      6.0    -48.0    140.0     72.0
    0.0002   6.0      0.0     50.0
 4000.0      0.6      0.3      8.0      6.0      0.0     0.015
    4   ANALYSIS TYPE = 3 SUDDEN, = 4 INCREMENTAL
```

TABLE 2   TYPICAL INPUT FILE

A file with the initial equivalent spring stiffness is needed. The stiffness for each joint is required, but the program will assume that stiffness of the joints ommitted in the input are equal to the previous joint stiffness value. The joint and the stiffness values should be separated by blanks or commas. The file should be called Problem Name.SPR.

The file RUG.DAT that contains the roughness vector data should also be present in the disk.

To use the program, RMFORT version of the program name should be typed with the corresponding general data name.

**Example: DYNOPAV < Problem Name . DAT**

To use Langling FORTRAN version of the program for 386 machines in which problems with more than 75 joints and 110 elements can be solved, the program should be run in the following manner:

**UP DYNOPAV < Problem Name.DAT**

### 4.a.3 Output

The DYNOPAV program generates the following output files at the step interval specified in the data.

1. Problem Definition Data
   file name = Problem Name.RES

2. Displacement and Acceleration
   file name = Problem Name.DIS

3. Displacement and Acceleration due to Temperature and Dead Load
   file name = Problem Name.TDI

4. Moment Resultant at Joints for Temperature and Dead Load
   file name = Problem Name.TSX

5. Moment Resultant at Joints for Dynamic Analysis
   file name = Problem Name.SX1

6. Principal Moment Resultants at Joints or due to Temperature and Dead Load
   file name = Problem Name.TSI

7. Principal Moment Resultant at Joints for Dynamic Analysis
   file name = Problem Name.SP1

8. Soil Reactions
   file name = Problem Name.SOI

9. Sum of Soil Reactions
   file Name = Problem Name.SSO

In addition, the program generates two files that are used by the graphical crack visualization program (CRACK) or the program PRICRACK that produce a listing of the crack formation sequence. These files are:

1. Problem Name . GEO
2. Problem Name . CRA

The output file could be obtained with a PRINT command, a word processor, SYMPHONY, or any other software since they are written in ASCI.

## 4.b **Graphical Input for Pavement Program (GRINPAV)**

### 4.b.1 Description

The GRINPAV program is a user friendly computer program that consists of graphical menus and tables designed to provide the interface information required to execute DYNOPAV program. The program was developed using the graphical tools developed by Pesquera [18]. In appendix B, information about drivers needs and configuration file requirements are given. In Figure 12, a general flowchart of the GRINPAV program is presented.

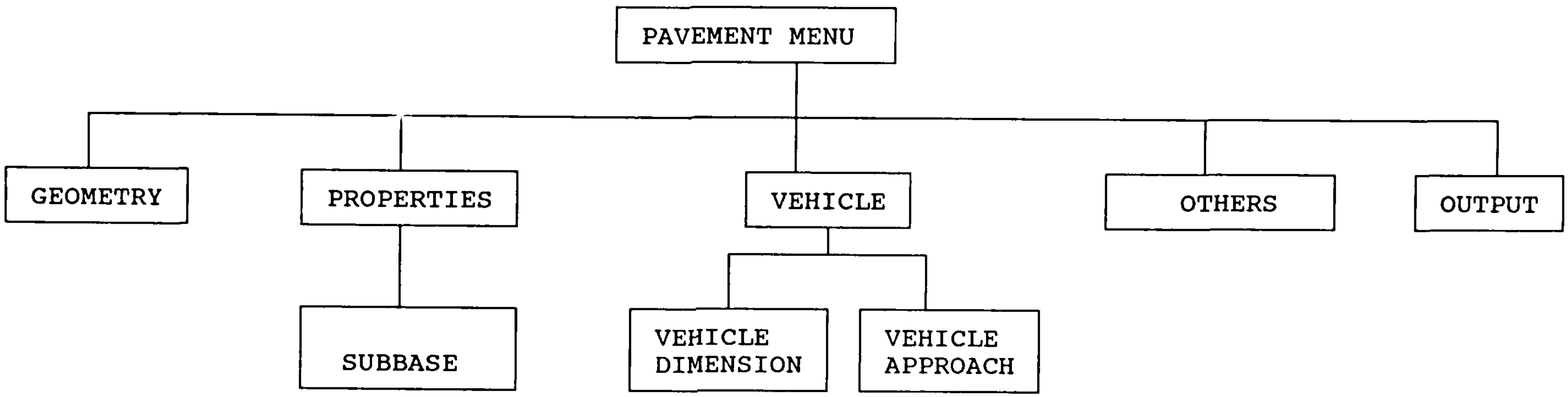



Figure 12. Flowchart Illustrating GRINPAV Screens

Essentially the program consists of the following major screens:

a. Pavement Menu
b. Geometry Menu
c. Properties Menu
d. Vehicle Menu
e. Others Menu
f. Output Menu

4.b.2 Input Data

The input data process is performed through the menus that are listed in Figure 12. A description of the main features of each screen is discussed below.

**Pavement Menu:** **PAVEMENT** Menu is the opening screen of GRINPAV (see Figure 13). It provides access to the other input data screens, namely, GEOMETRY, PROPERTIES, VEHICLE, OTHERS, and OUTPUT. To create a new file the option **NEW** is used. Existing data files can be retrieved using the **READ** option. The **SAVE** option creates a file named **Problem Name.dat** which contains all the raw data generated during the current working session.

The **ANALYSIS** option generates the following four files required for the execution of the dynamic non-linear analysis program (DYNOPAV):

- problem name.ANA
- problem name.COR
- problem name.INC
- problem name.SPR.

To finish the working session the **EXIT** option is selected.

**Geometry Menu:** The **GEOMETRY** menu shown in Figure 14 is used to provide the geometric characteristics of the pavement slab being considered, namely slab width, slab length, thickness, finite

Screen 1. Pavement Menu

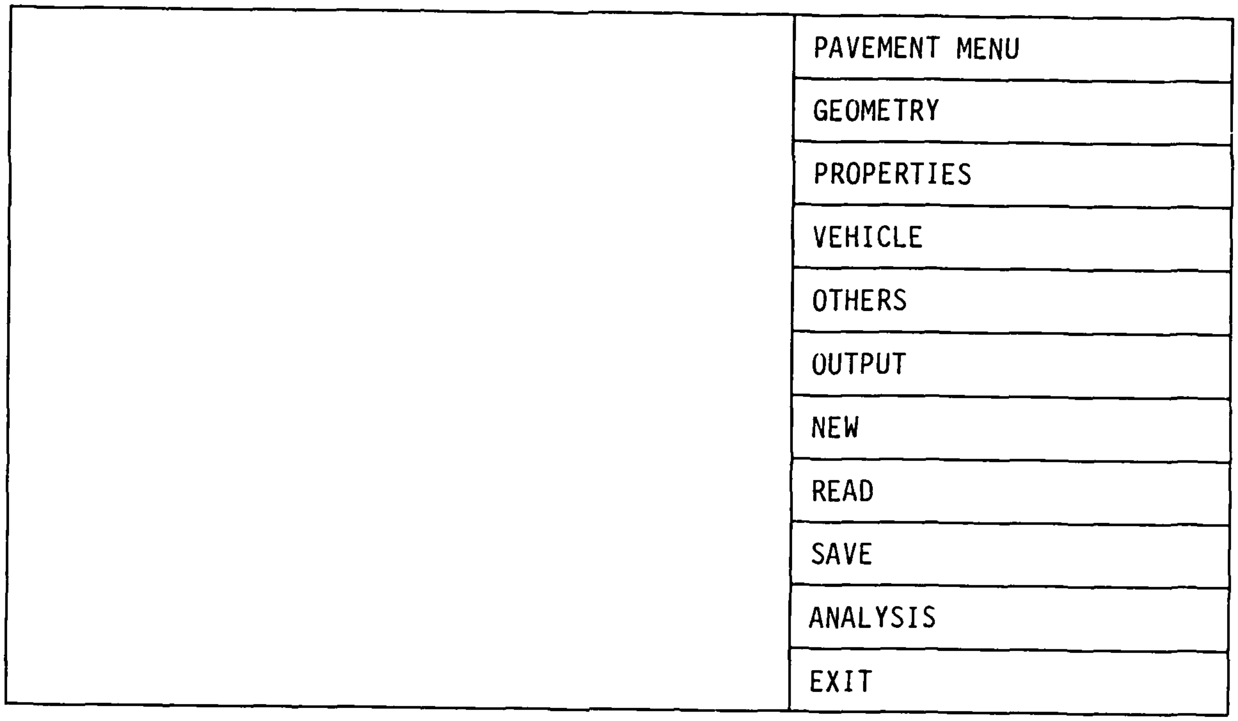



Figure 13. Pavement Menu

Screen 2. Geometry Menu

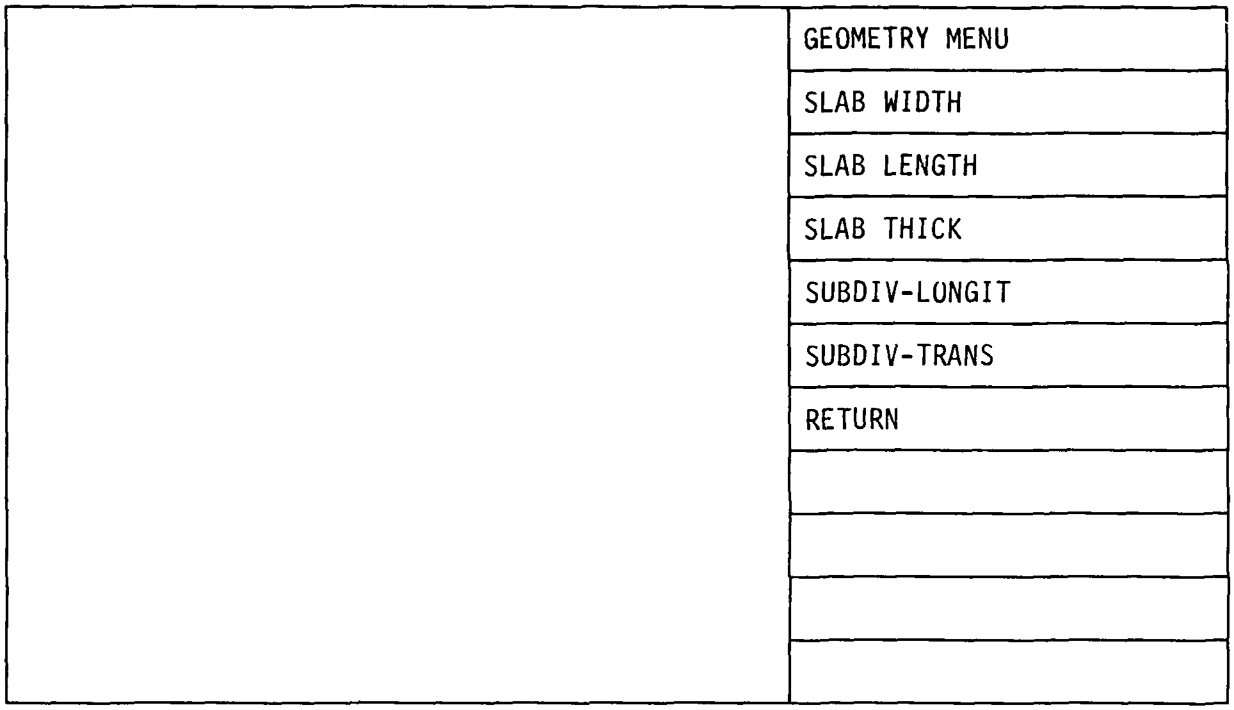



Figure 14. Geometry Menu

element mesh subdivision in the longitudinal and transverse direction. The default values for slab width and length are 12 feet and 20 feet, respectively. The default value for slab thickness is 1 ft, while the mesh subdivisions are 12 and 8 feet in the longitudinal and transverse direction, respectively.

Once this information is input, the user can return to the opening menu by selecting the **RETURN** option.

**Properties Menu:** This menu is used to input the information regarding the materials properties associated with the rigid pavement slab and granular subbase (see Figure 15). Surface roughness information is also provided in this screen.

The material properties input for rigid pavements include the compressive strength of the concrete @ 28 days ($f'_c$), the poisson ratio ($\mu$) as well as the cracking stress. The default values for $f'_c$ and poisson ratio are 4 ksi and 0.2, respectively. The cracking stress is set at 0.474 ksi.

Other options included in the properties menu are the **FRICTION ANGLE** and **SOIL COHESION**. These parameters are used to determine the principal stresses based on the Mohr-Coulomb failure theory. The default values for the angle of friction is 20° and the corresponding soil cohesion is .015 ksi.

The **ROUGHNESS** option is included in this menu and corresponds to the amplitude in inches perceived by the vehicle while crossing the slab. The default value for roughness is 0.50 inches.

Screen 3.  Properties Menu

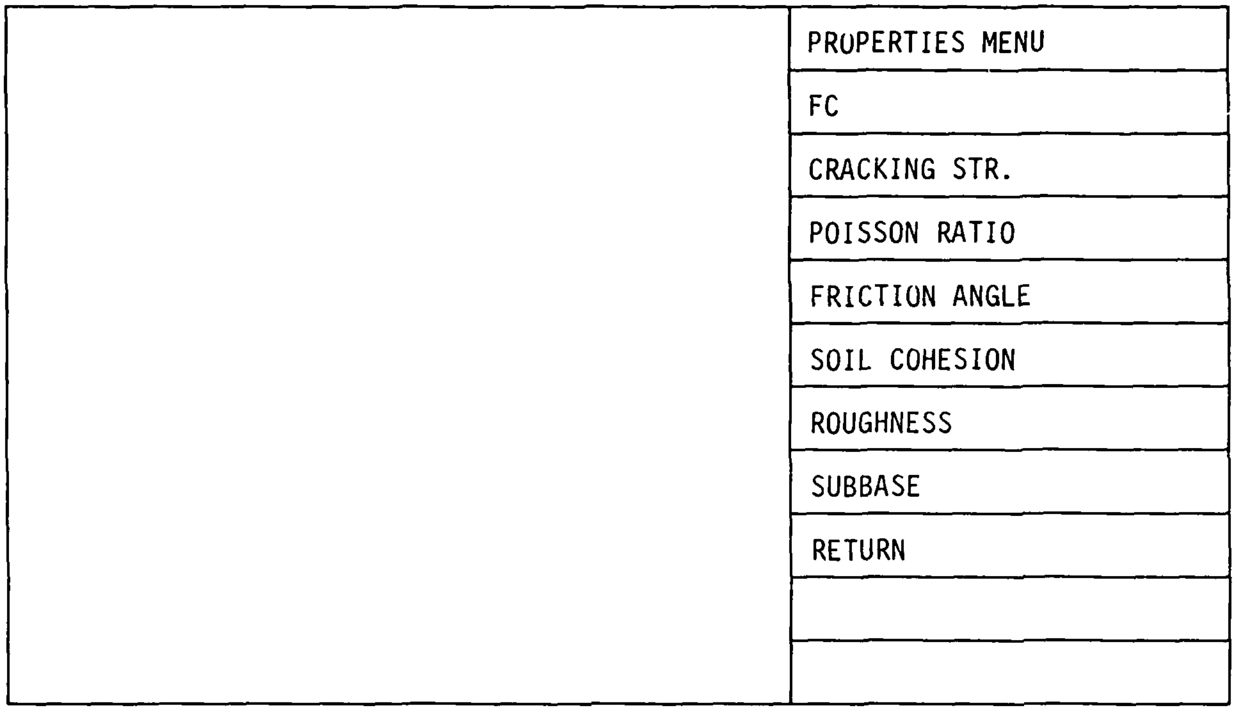



Figure 15.  Properties Menu

When the **SUBBASE** option is selected, another menu is displayed on the screen (see Figure 16). The **DEPTH** option corresponds to the subbase thickness in feet. The **STRESS DEPTH** option is the depth at which the stress analysis is performed within the subbase layer. The stress depth shall always be less than the subbase thickness (i.e. depth). The corresponding default values are 5 and 3 feet. The **MOD. SUBGRADE** option corresponds to the modulus of subgrade reaction based on the dense liquid concept expressed in $lbs./in^3$. The default value of k is 300 psi.

The options **CONSTANT** $K_1$ and $K_2$ correspond to the coefficients required to determine the subbase resilient modulus. Guidelines for $K_1$ and $K_2$ were previously presented in Table 1 and default values are 4,000 and 0.6, respectively.

The option **SOIL POISSON** corresponds to the subbase poisson ratio and the default value is 0.35. The **RETURN** option is used to return to the **PROPERTIES** menu.

**Vehicle Menu:** This screen is used to input the characteristics of the vehicle used in the analysis (see Figure 17). A vehicle can consist of either an aircraft or a truck. The option **NUMBER OF AXLE**, as defined herein, is the number of transverse axles with paired wheels or point of contacts which will be used to define the wheel configuration. The term axle is not necessarily associated with a truck. In Figure 18, the wheel configuration of a particular vehicle is shown as well as the computation of the number of axles. In this example, the number of axles with

Screen 6. Subbase Menu

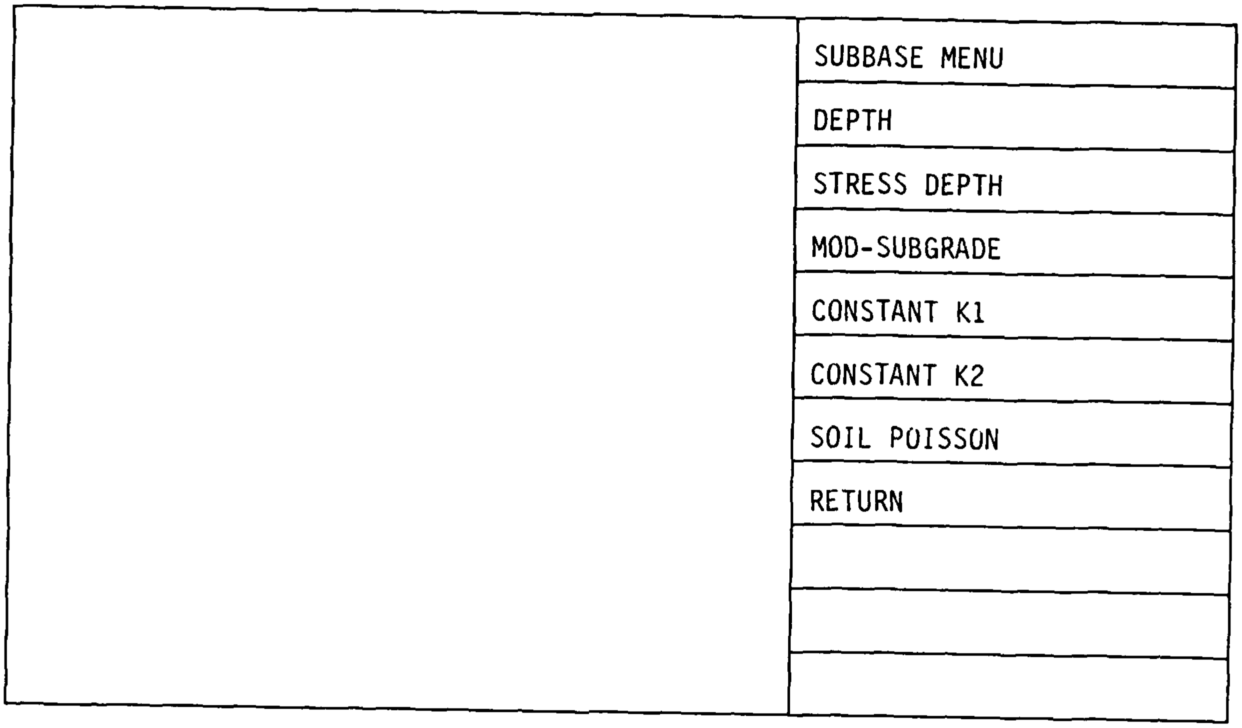



Figure 16. Subbase Submenu

Screen 4. Vehicle Menu

| |
|---|
| VEHICLE MENU |
| NUMBER OF AXLE |
| ROT. MASS X |
| ROT. MASS Y |
| VEHI-DIMENSION |
| WHEEL LOAD |
| WHEEL STIFFNESS |
| TIRE STIFFNESS |
| VEHI-APPROACH |
| MASS FACTOR |
| RETURN |

Figure 17. Vehicle Menu

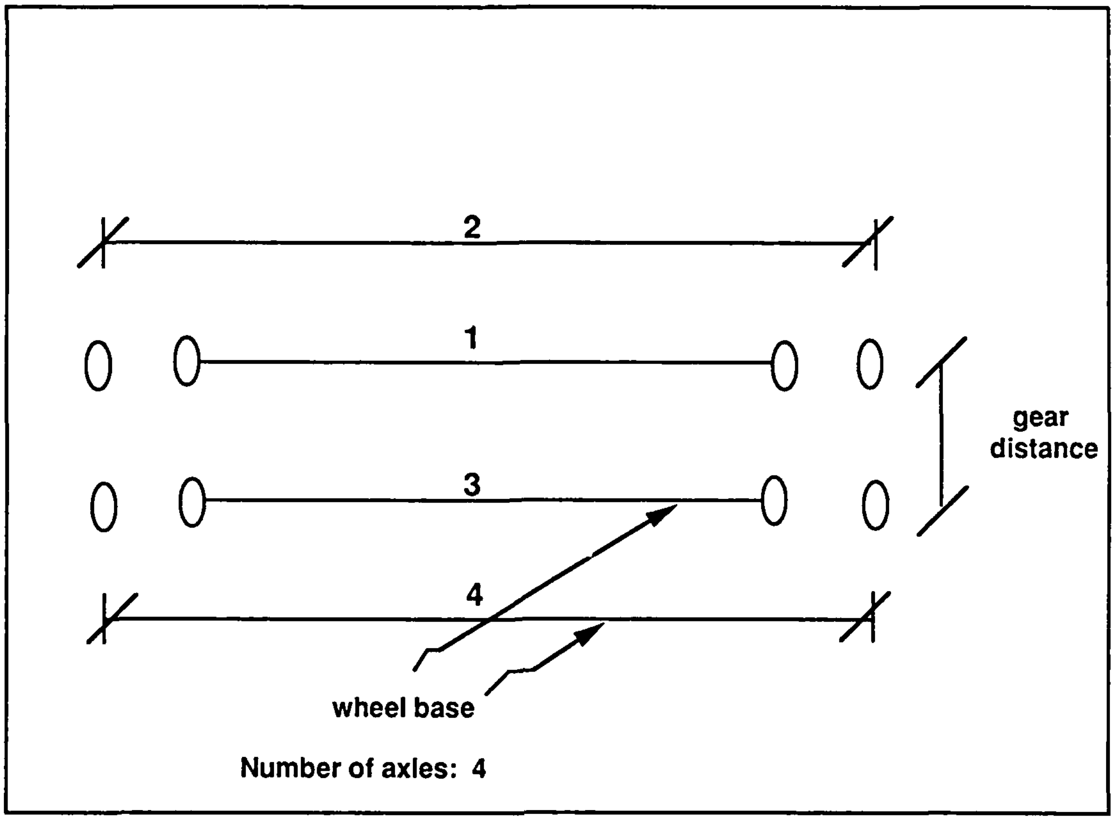



Figure 18. Vehicle Wheel Configuration Nomenclature And Sample Computation Of Number Of Axles For Paired Wheels.

two wheels is 4. It can be observed that axles 1 and 2 are on the same transverse location whereas axles 3 and 4 are located at a gear distance that must be specified. If the user wants to specify more than two contact points per axle, it can define two axles in the same relative location. The default value for number of axles is 2.

The options for **ROT. MASS X** and **ROT. MASS Y** correspond to the rotational mass in the x and y direction for the analysis vehicle. The input values shall be in terms of k-$sec^2$. The default values for rotational mass in x and y are 16 and 42 k-$sec^2$, respectively.

When the **VEHI-DIMENSION** option is selected, a new menu is displayed as shown in Figure 19. Two entries are required for each option. The **WHEEL BASE** option corresponds to the wheel spacing within an axle or gear. The default value is 6 feet. The **GEAR DISTANCE** option corresponds to the spacing between axles or the longitudinal spacing between wheels in a twin-tandem arrangement. The default value for the distance between axle one and two is 14 feet and is representative of the spacing between axles in a truck. The **RETURN** option is used to return to the **VEHICLE** menu.

The **WHEEL LOAD** option corresponds to the weight of individual wheels in an axle or gear in kips. One entry is required for each axle. The default values for two axles are 8 and 48 kips, respectively.

Screen 7. Vehi-Dimension

| | |
|---|---|
| | VEHI-DIMENSION |
| | WHEEL BASE |
| | GEAR DISTANCE |
| | RETURN |
| | |
| | |
| | |
| | |
| | |
| | |
| | |

Figure 19. Vehi-Dimension Submenu

The **WHEEL STIFFNESS** option corresponds to the stiffness of the wheels in a particular axle expressed in kips/feet. The default values for two axles are 12 and 72 kips/ft.

The **TIRE STIFFNESS** option is also presented in terms of kip/feet. The default values for two axles are 70 and 140 kips/ft, respectively. In Figure 11 a vehicle representation is shown in which the vehicle wheel stiffness ($K_v$) and the tire stiffness ($K_t$) are represented by springs.

If the **VEHI-APPROACH** option is selected, a submenu is displayed on the screen for the selection of one of the two options (see Figure 20). The first option, termed **INCREMENTAL**, applies when a vehicle enters the slab coming from a previous slab. In this case the vehicle is gradually approaching the slab to be analyzed. The input information required for this condition corresponds to the distance from the pavement edge at which the vehicle will enter the slab. The **SUDDEN** option corresponds to the condition when the vehicle makes a sudden contact with the pavement at a given distance from the transverse joint. The input information required for this condition are the x and y coordinates that define the location where the first axle or gear of the vehicle will make a sudden impact.

The **VELOCITY** option corresponds to the speed in ft/sec that the vehicle is moving through the slab for determining the stresses. The default value is 50 ft/sec. The **RETURN** option is used to return to the **VEHICLE** menu.

Screen 8. Vehi-Approach

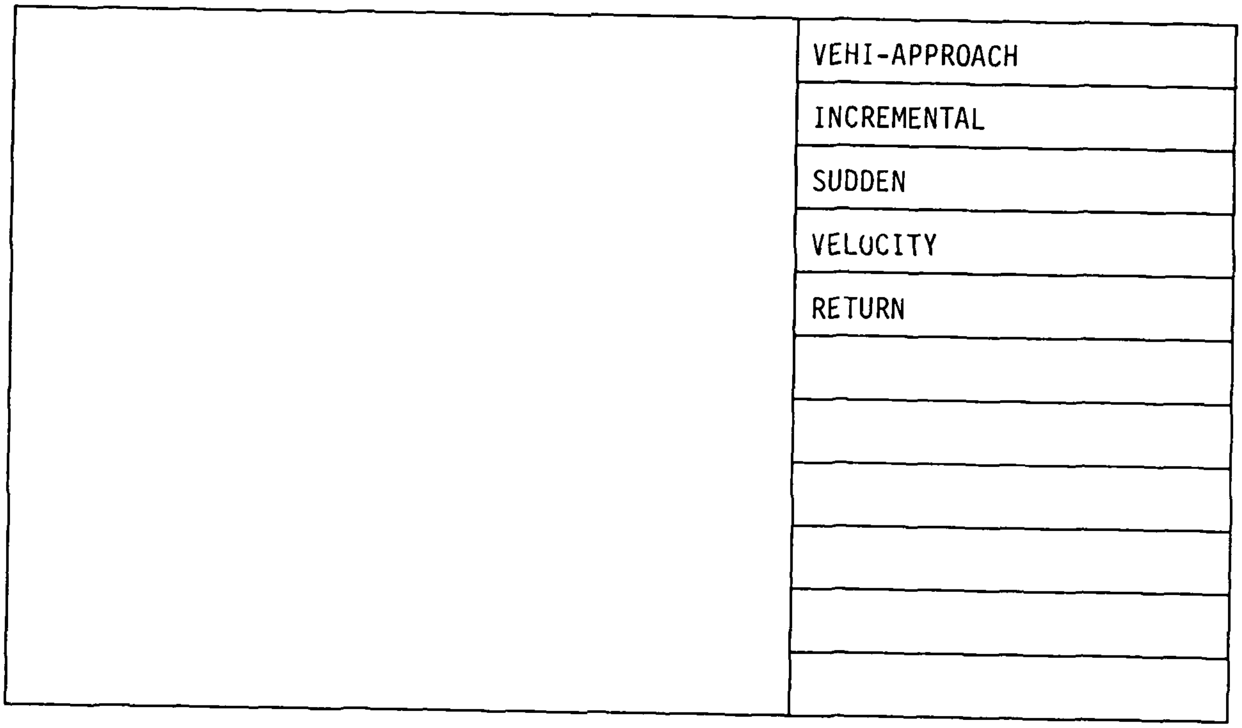



Figure 20. Vehicle Approach Submenu

The last option in the **VEHICLE** Menu named **MASS FACTOR** corresponds to a factor that determines the percent of mass that will be assigned to the main body of the vehicle. The rest of the mass will be assigned to the tire level in proportion to the axle load. The default value is 0.9.

The **RETURN** option is used to return to the **PAVEMENT** menu.

**Others Menu:** The **OTHERS** menu shown in Figure 21 was developed to input information regarding temperature effect on the slab. The gradients between the top and bottom of the slab (i.e **TEMP-GRADIENT** option) as well the coefficient of thermal expansion (i.e **TEMP-COEFFICIENT** option) can be input with this option. The default values for temperature gradient is 0°F and $5 \times 10^{-5}$ in/in/°F for the coefficient of thermal volume change for concrete.

The **TIME INCREMENT** option is used to specify the time increment of each step of the dynamic numerical integration. The default value is $0.2 \times 10^{-3}$. The **TOTAL # INCREMENT** option specifies the total number of increments for printing the dynamic numerical integration. If the value of zero is specified, the program computes the length of the slab and vehicle and prints the displacement and acceleration, moment resultant, soil reactions and sum of soil reactions for the entire slab. The **RETURN** option returns the user to the opening **PAVEMENT** menu.

Screen 5. Others Menu

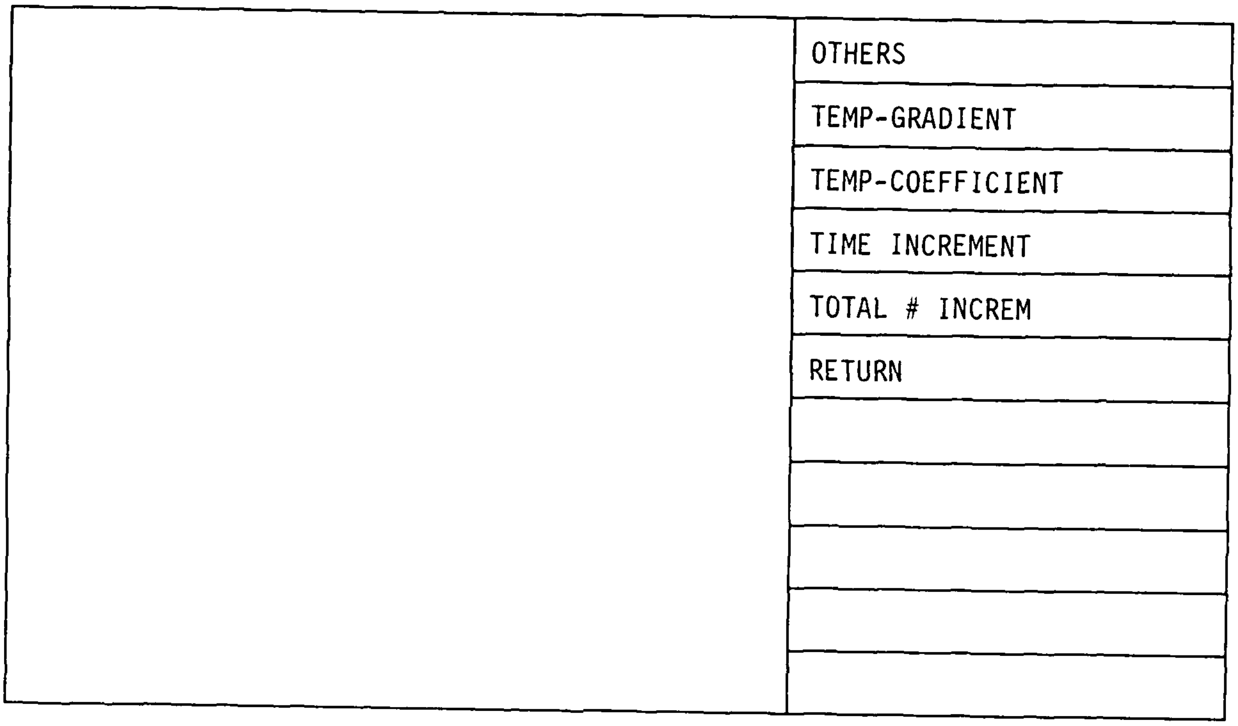



Figure 21. Others Menu

**Output Menu:** The **OUTPUT** menu shown in Figure 22 provides the user with four types of data, namely, displacement and acceleration, moment resultant, soil reaction, and summation of soil reactions. The user can specify the interval at which the computations will be printed. The default value for displacement and acceleration computations, moment resultant and soil reactions is 100. For the summation of the soil reactions, the default value is set to 10. The **RETURN** option is used to return to **PAVEMENT** menu.

4.b.3 Output

The output of program GRINPAV are the four files generated by the **ANALYSIS** option and the **Problem Name.dat** generated by the **SAVE** option. These files contain input data required for the execution of DYNOPAV program and are described in detail in section 4.a.2.

Screen 9. Output Menu

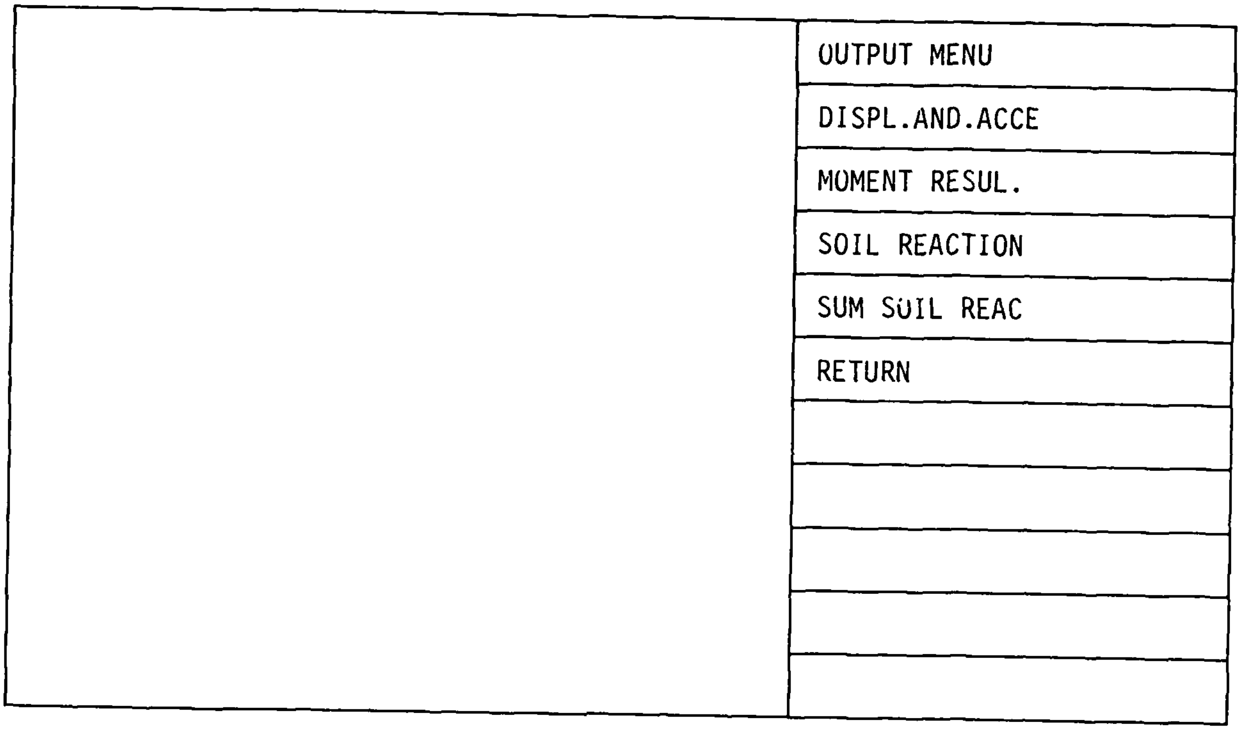



Figure 22. Output Menu

## 4.C Crack Visualization Program (DRACRACK)

### 4.C.1. Description

DRACRACK is a special purpose program that provides a graphical illustration of the concrete cracking as a vehicle moves over the pavement. The illustration on the video display terminal shows the boundaries of the pavement, the vehicle tires as they move across the pavement, and the cracks formed as a result.

### 4.C.2. Input

The DRACRACK program requires three files as input. Two of these are generated by the program DYNOPAV. The third one must be created by the user.

The files created by DYNOPAV are the following:

Problem Name.GEO -- file that contains information about the pavement geometry, element, and vehicle information.

Problem Name.CRA -- file that contains information about the time interval, location, and orientation of the cracks.

The additional general data file to be created by the user should contain the following information:

1) Problem Name -- eight characters or less without extension

2) TOP or BOT to identify the surface for which cracks will be drawn

3) Length of crack in millimeters

4) Drawing Spread Parameter -- an integer number from one to ten thousand; the lower the number, the lower the velocity.

To run the program the following command must be entered:

DRACRACK < General Data File

### 4.C.3 Output

The program will draw on the computer screen the pavement, the track of the vehicle tires across the pavement, and the cracks as they form.

## 4.d Program to Print Crack Formation Output (PRICRACK)

### 4.d.1 Description

The program that prints crack formation output is a special purpose program designed to produce an easy to understand output of the crack formation sequence.

This program uses row data from the same files used by the DRACRACK program and generated by the DYNOPAV program. It then creates an easy to interpret file with the sequence of the generated cracks.

### 4.d.2 Input

The PRICRACK program requires three files to operate. Two of these are generated by the program DYNOPAV. The third one is to be created by the user.

The files created by DYNOPAV are the same ones used by the program DRACRACK for the visualization of the crack formation (Problem Name .GEO, Problem Name .CRA).

The additional file needed contains only the name of the problem and can have any user selected name.

To run the program the following command must be typed:

**PRICRACK < General Data File Name > File Name to Store Output**

### 4.d.3 Output

The PRICRACK program generates a file with the number of steps that a crack change generates, the element affected, the

location of the crack and the angle of the crack axis with respect to the global coordinates.

For each subelement within an element, information for the top and bottom surface is given describing the crack formed along axis one or two or along both axes.

# CHAPTER 5

## PAVEMENT BEHAVIOR

A number of problems have been analyzed using the program DYNOPAV in order to study the behavior of concrete pavement under the effect of a moving vehicle.

Different parameters were modified one at a time to determine the influence in the behavior and at the same time trying to verify the correctness of the analytical procedure developed. There are currently no other analytical tools that could be used to compare results, therefore, the theory developed has been evaluated from the point of view of how logic the results look based on previous knowledge. Also, during the problem solving procedure, parameters such as the time interval had been modified to observe how consistent are the solutions and to determine the convergence of solutions.

The same slab geometry had been used for all the problems studied as well as the same vehicle characteristics. A 12 by 20 feet slab with a thickness of one foot was used. The slab was subdivided in a 6 x 6 mesh with a total of 72 triangular elements and 49 joints. The vehicle parameters used as input in the scenarios analyzed are summarized in Figure 11.

For the subbase, a depth of eight feet (8'-0") and a stress computation elevation of six feet (6'-0") were used in all examples.

A summary of the parameters of the different scenarios analyzed is presented in Table 3. As can be observed from this table, a total of thirteen analyses were performed, with

Table 3: Scenaries Analyze

| PROBLEM NAME | VEHICLE VELOCITY (ft/sec) | ROUGHNESS AMPLITUDE (in) | TIME INTERVAL (sec) | SOIL COEFFICIENT K1 | SOIL COEFFICIENT K2 | FRACTURE ANGLE | SOIL COHESION COEFFICIENT (ksi) | CONCRETE CRACK STRESS (k/ft) |
|---|---|---|---|---|---|---|---|---|
| EXAMPLE 1 | 50.00 | 0.00 | C.0002 | 4000.00 | 0.60 | 0.00 | 0.015 | 1000.00 |
| EXAMPLE 2 | 100.00 | 0.00 | 0.0002 | 4000.00 | 0.60 | 0.00 | 0.015 | 1000.00 |
| EXAMPLE 3 | 100.00 | 0.00 | 0.0001 | 4000.00 | 0.60 | 0.00 | 0.015 | 1000.00 |
| EXAMPLE 4 | 50.00 | 0.00 | 0.0002 | 6000.00 | 0.70 | 0.00 | 0.015 | 1000.00 |
| EXAMPLE 5 | 50.00 | 0.25 | 0.0002 | 4000.00 | 0.60 | 0.00 | 0.015 | 1000.00 |
| EXAMPLE 6 | 50.00 | 0.50 | 0.0002 | 4000.00 | 0.60 | 0.00 | 0.015 | 1000.00 |
| EXAMPLE 7 | 50.00 | 0.00 | 0.0002 | 5000.00 | 0.50 | 40.00 | 0.00 | 56.10 |
| EXAMPLE 7B | 50.00 | 0.00 | 0.0002 | 5000.00 | 0.50 | 30.00 | 0.00 | 45.00 |
| EXAMPLE 7G | 50.00 | 0.00 | 0.0002 | 5000.00 | 0.50 | 20.00 | 0.00 | 45.00 |
| EXAMPLE 7H | 50.00 | 0.00 | 0.0002 | 5000.00 | 0.50 | 40.00 | 0.00 | 45.00 |
| EXAMPLE 8 | 50.00 | 0.25 | 0.0002 | 4000.00 | 0.60 | 40.00 | 0.00 | 45.00 |
| EXAMPLE 9 | 100.00 | 0.00 | 0.0001 | 4000.00 | 0.60 | 40.00 | 0.00 | 45.00 |
| EXAMPLE 9A | 100.00 | 0.00 | 0.0001 | 4000.00 | 0.60 | 40.00 | 0.00 | 30.00 |

variation in vehicle velocity, roughness amplitude, time interval, soil coefficients and concrete crack stresses.

In Appendix C, a set of sample outputs is given for moment resultants, soil pressure, joint displacement and crack formation description for three sample problem analyses.

In Figures 23 to 29 a comparison between a plot of the total dynamic reaction in the soil versus travel distance for different combination of problems is shown. In Figure 23, the results of Example 1 are compared with those of Example 2. The only difference in the input is the vehicle velocity. Due to the change in velocity, a variation in the behavior could be observed. In Example 2 (100 ft/sec), the peak respond occurred approximately at every two cycles of the peak response in Example 1 (50 ft/sec). This result is very logic.

From step 1 to step 1400 the peaks were very similar. This was not so after the rear axle entered the slab. After this, in most of the cases, the peaks are much smaller for the case with the higher velocity.

The contours for the moment resultant in x for step 1600 are shown in Figures 30 and 31 for examples 1 and 2, respectively. As can be observed, the behavior is very different. The maximum moment resultant selected from all the steps computed are larger for the cases with the lower velocity (Example 1).

The decrease in time interval by a half, from 0.0002 to 0.0001 seconds, didn't produce any significant difference in the behavior as is reflected by the plot of the sum of soil reactions. This can be observed from Figure 24. On the other

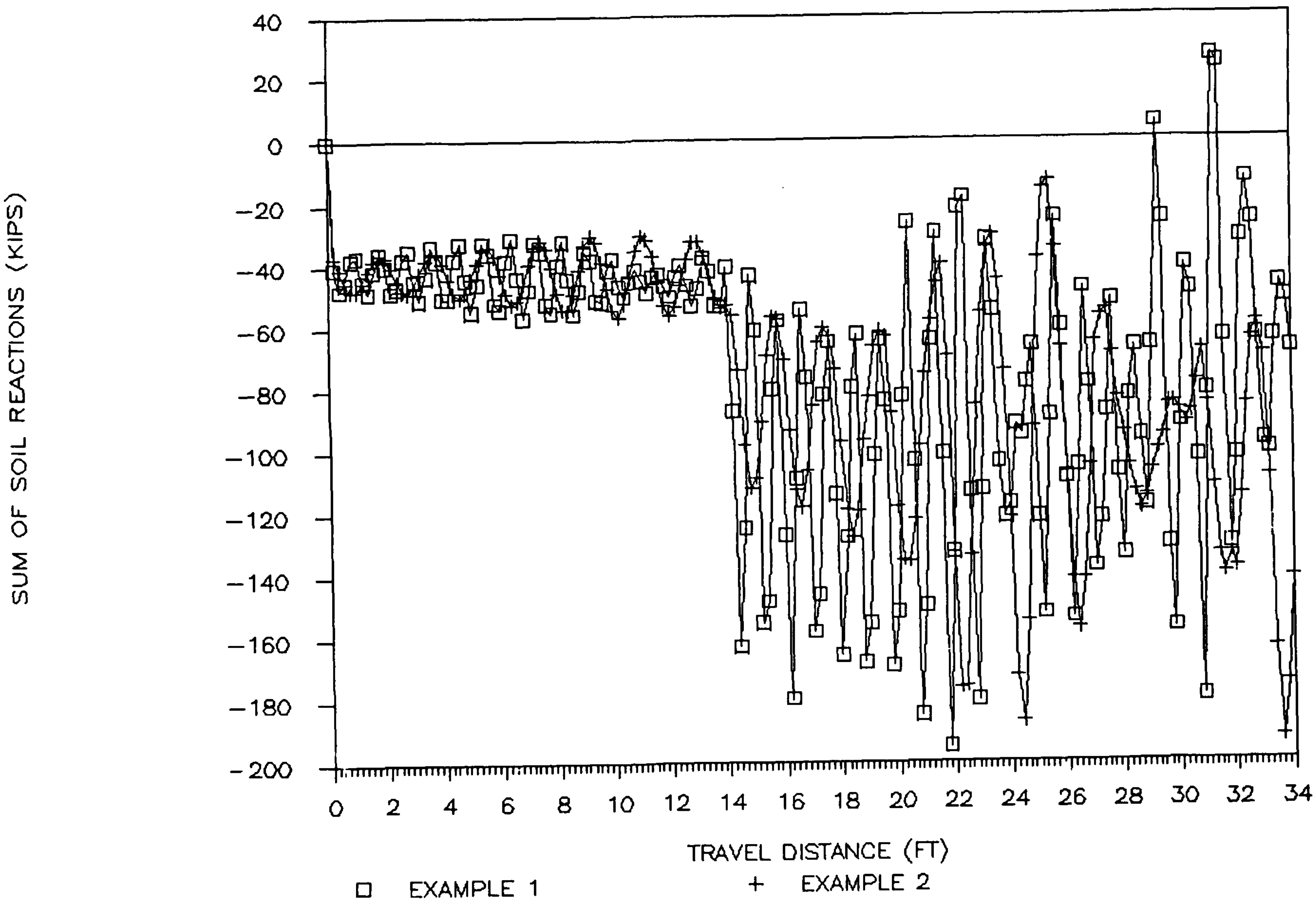



Figure 23. Sum of Soil Reaction for
Example 1 vs. Example 2

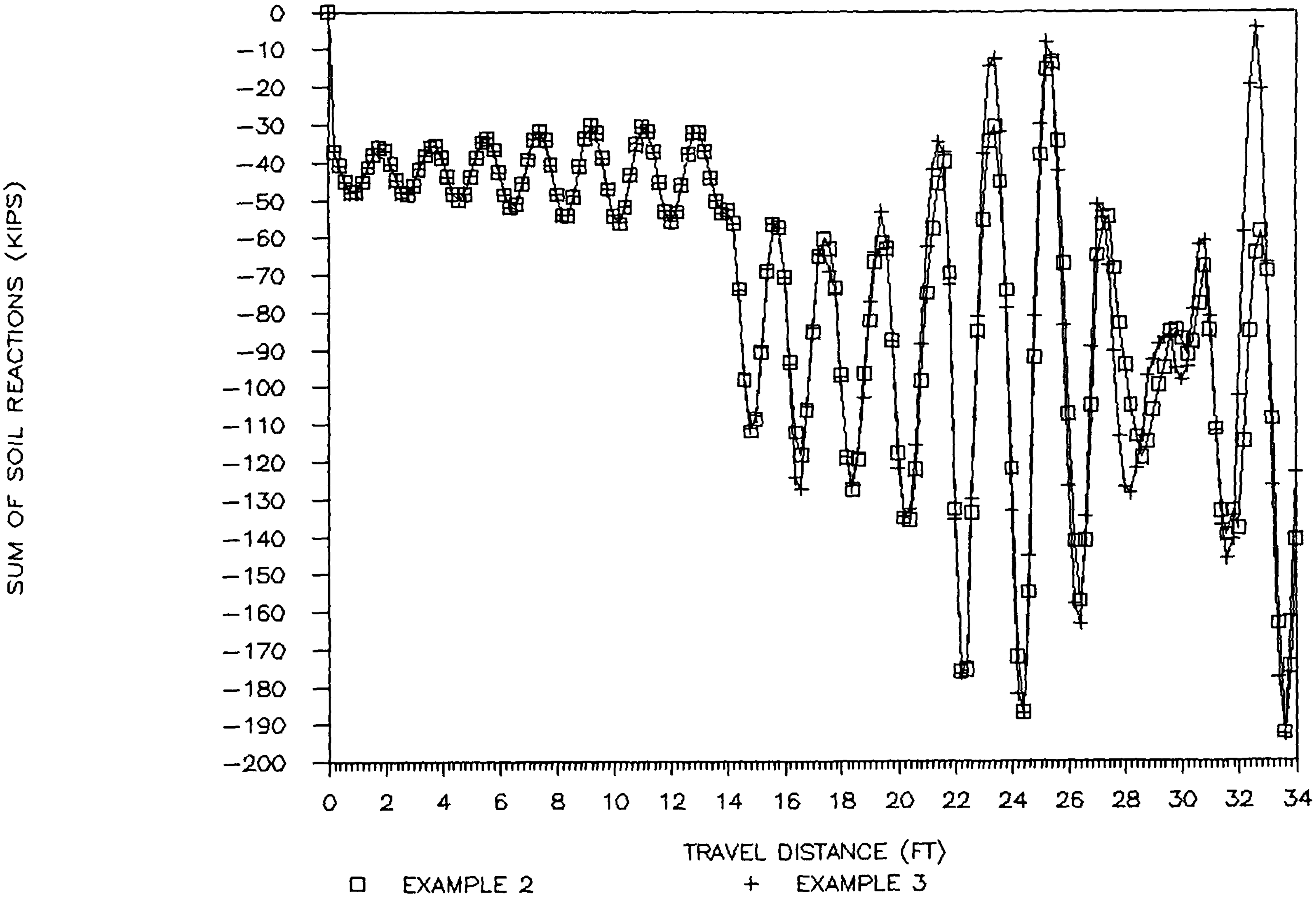



Figure 24. Sum of Soil Reaction for
Example 2 vs. Example 3

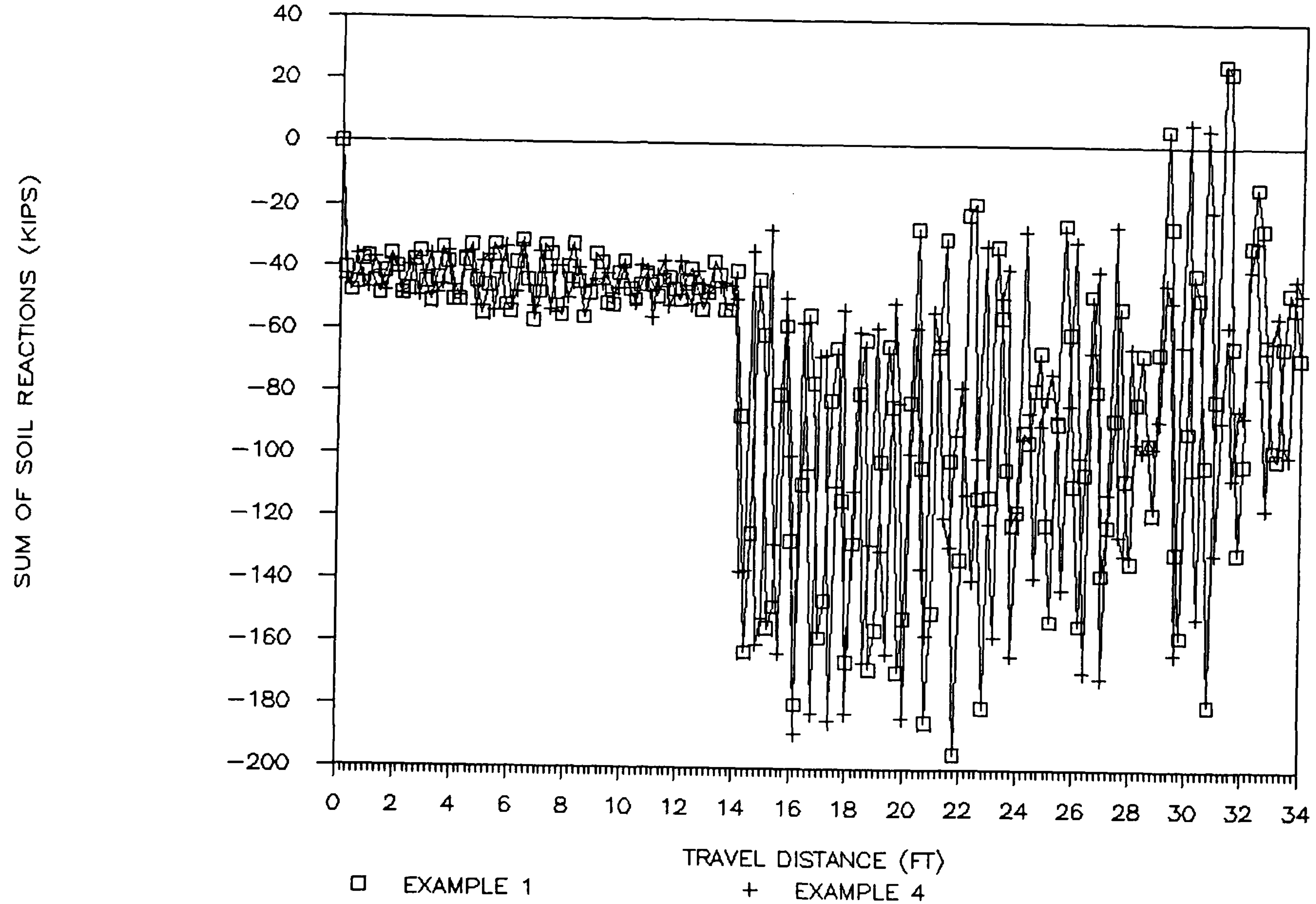



Figure 25. Sum of Soil Reaction for
Example 1 vs. Example 4

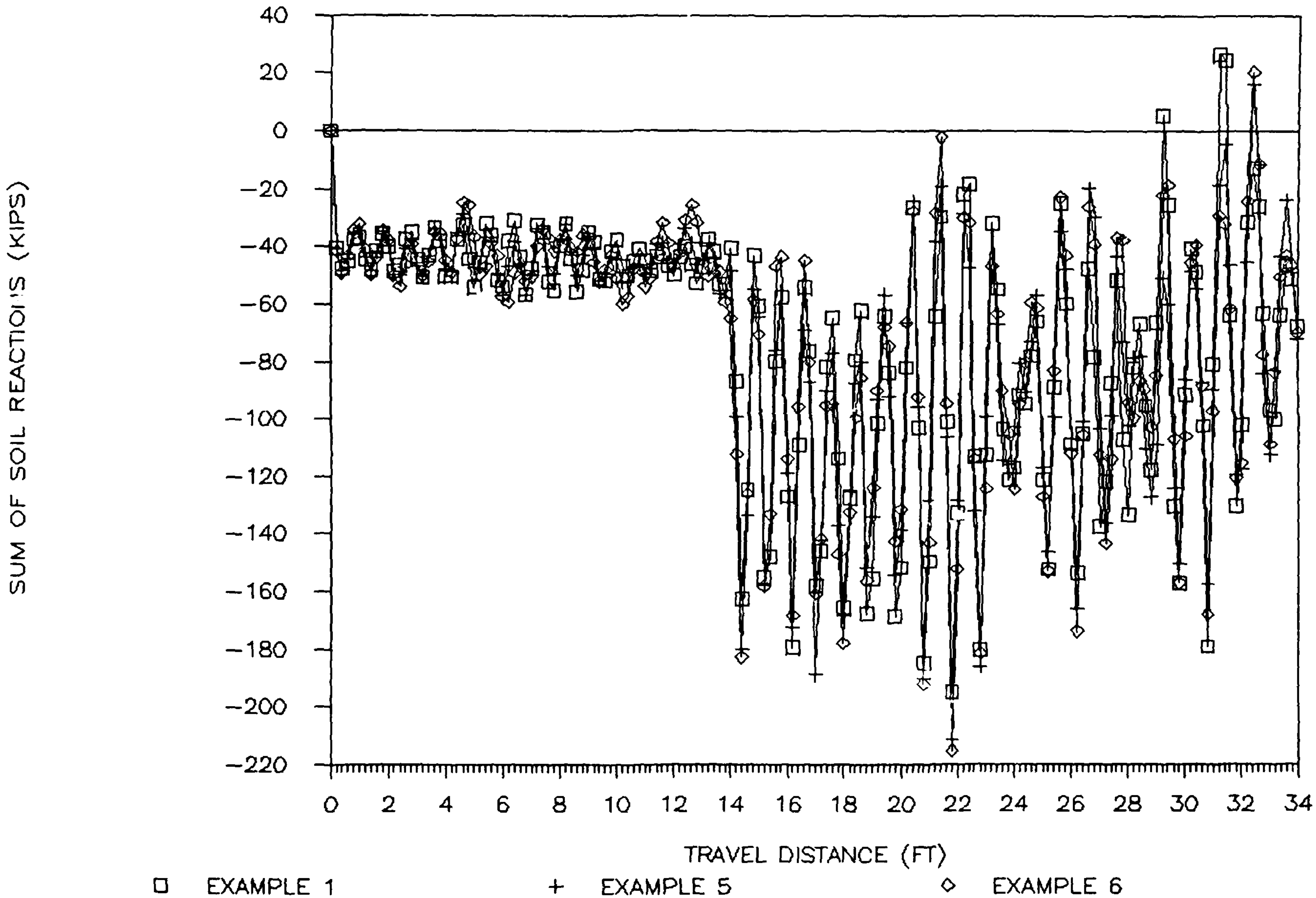



Figure 26. Sum of Soil Reaction for
Example 1 vs. Example 5 vs. Example 6

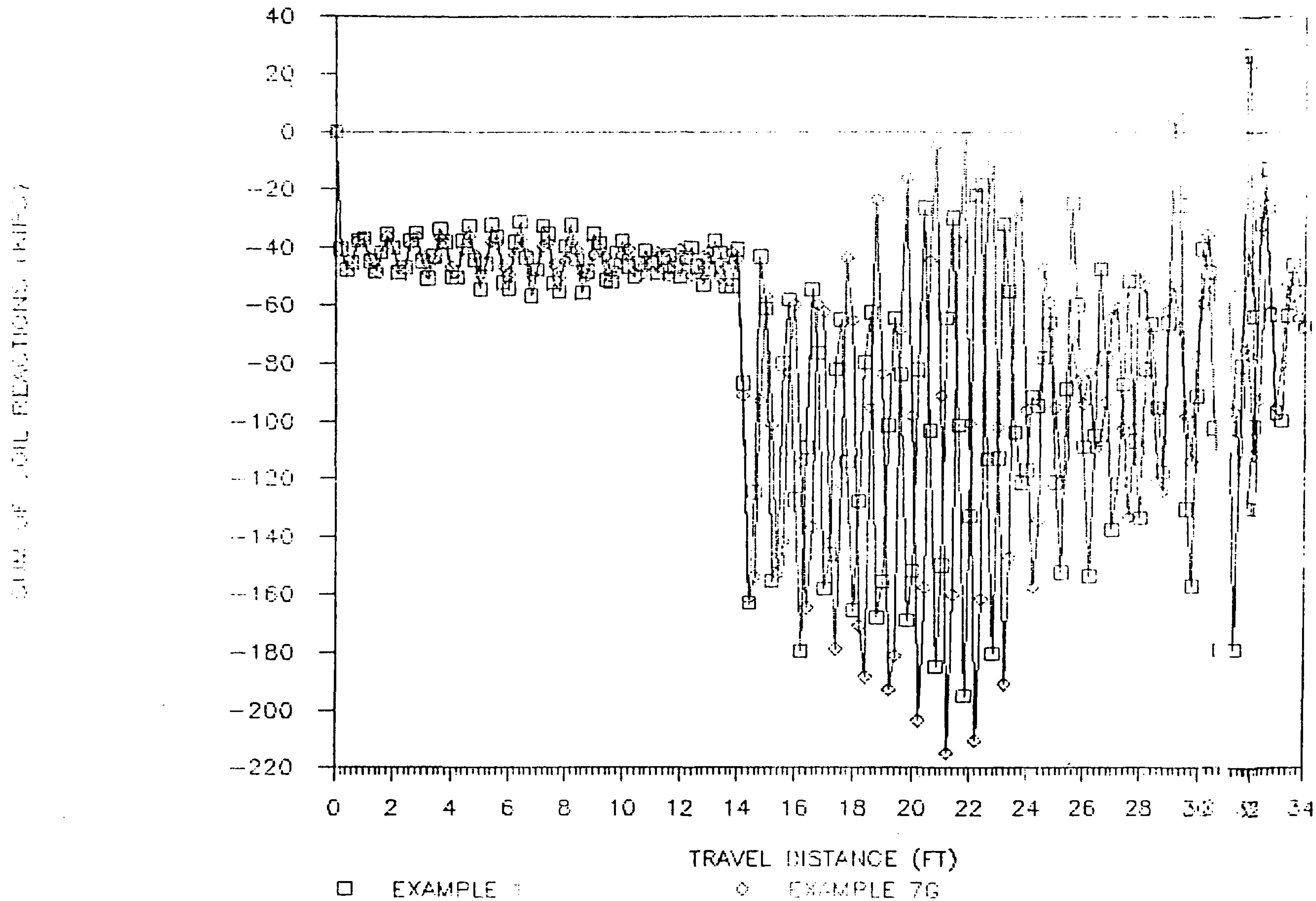



*Figure 27. Sum of Soil Reaction for Example 1 vs. Example 7*

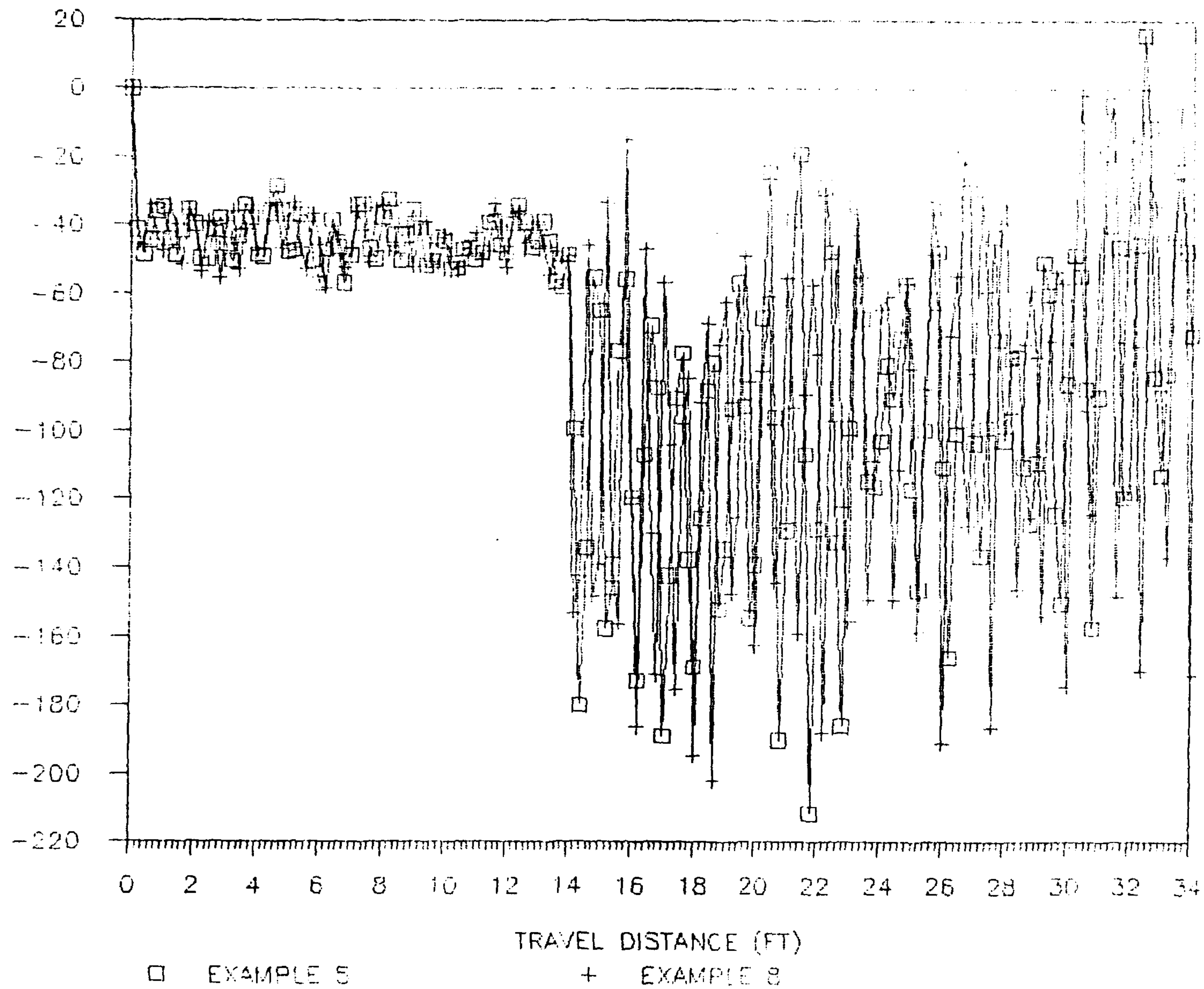



Figure 28. Sum of Soil Reaction for
Example 5 vs. Example 8

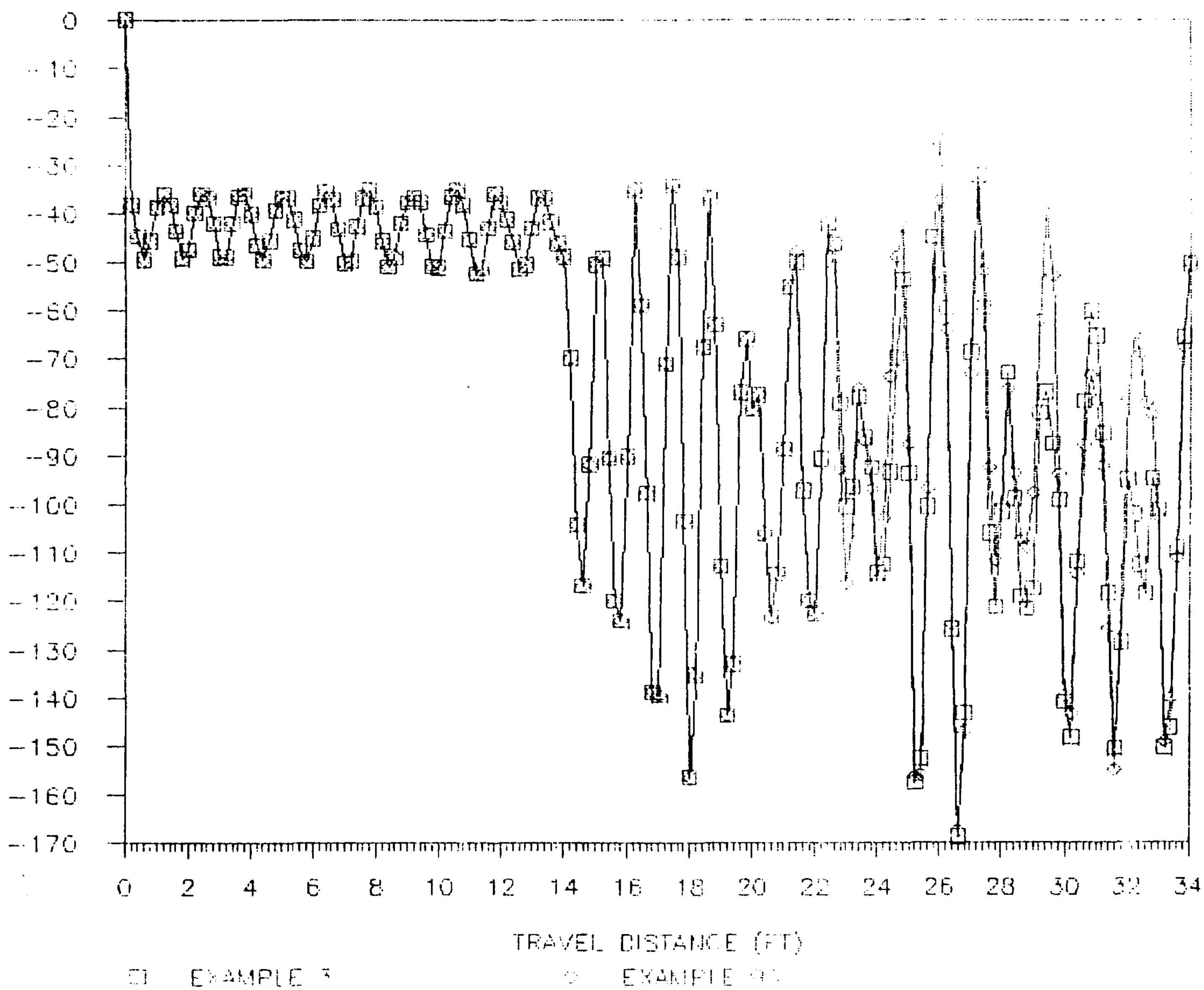



Figure 29. Sum of Soil Reaction for Example 3 vs. Example 9

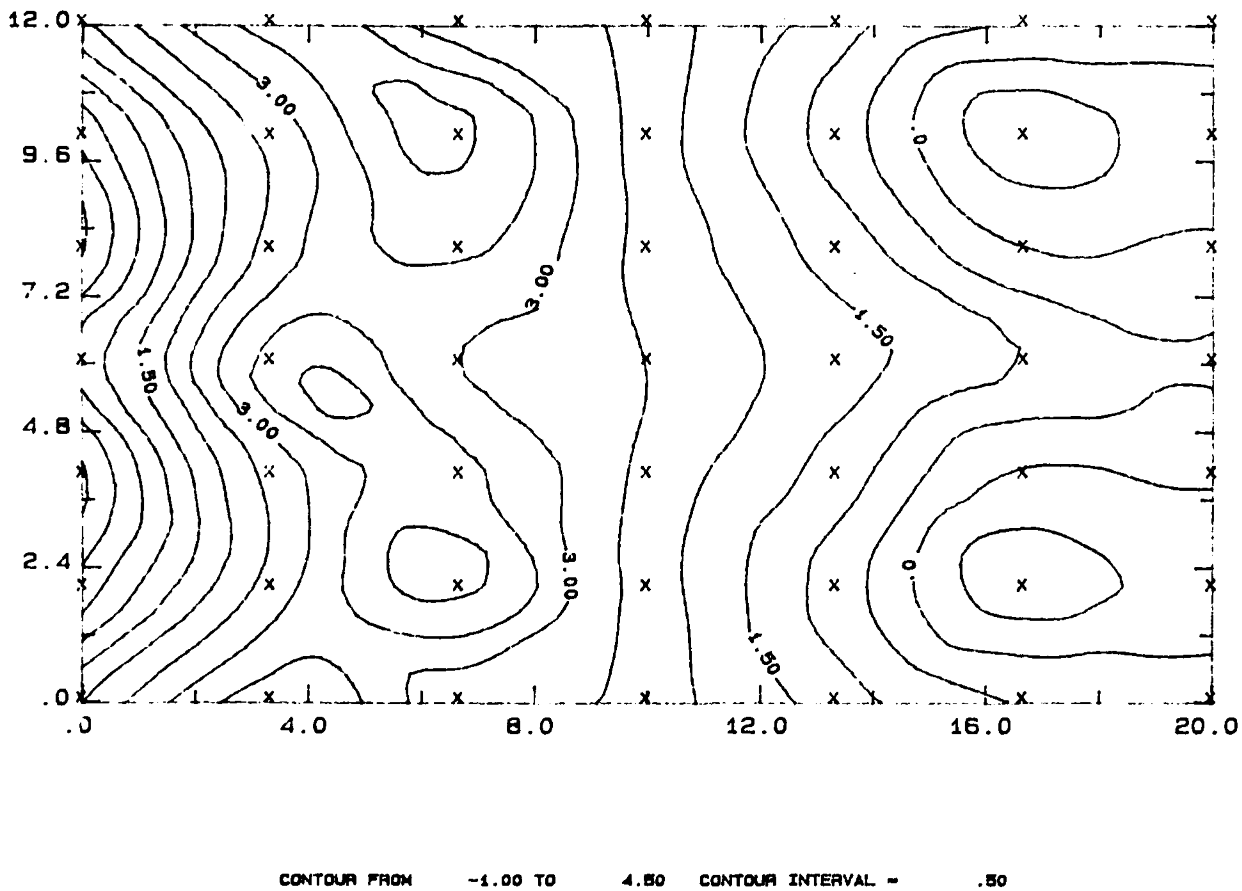
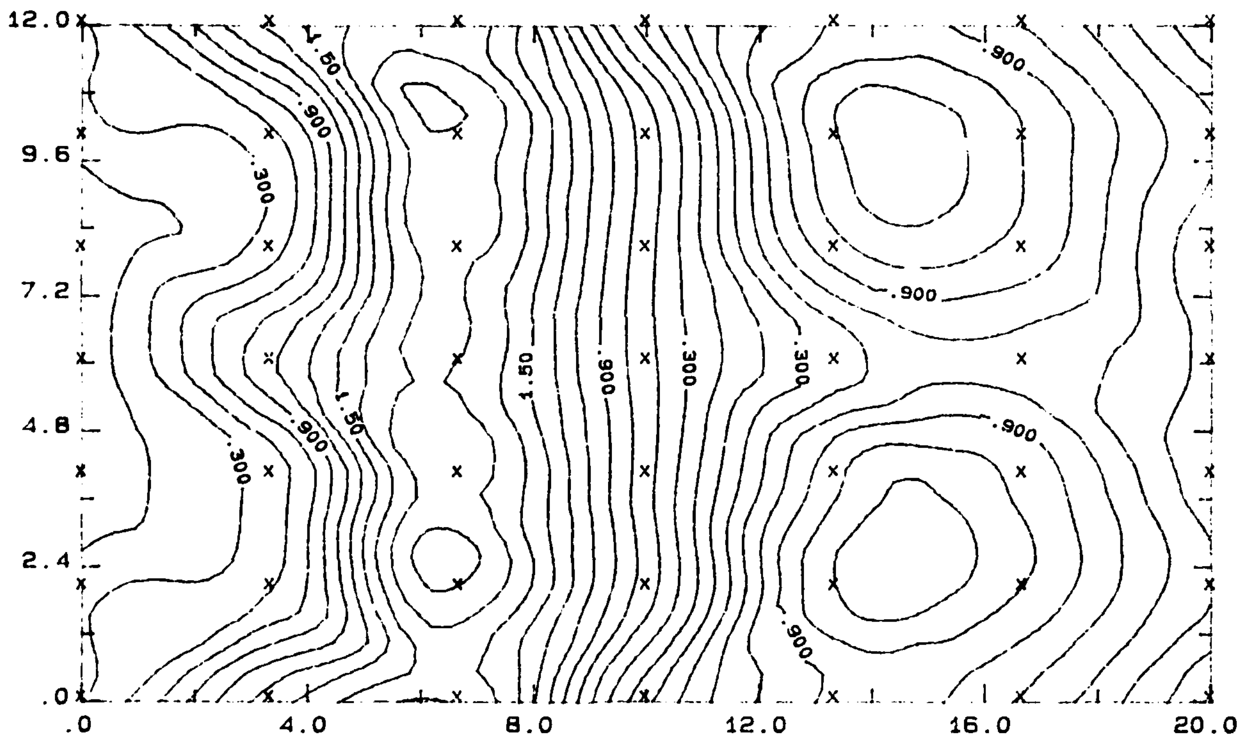



Figure 30. Contours for Moment Resultant in X for Example 1
Step 1600




CONTOUR FROM -1.50 TO 2.50 CONTOUR INTERVAL = .20

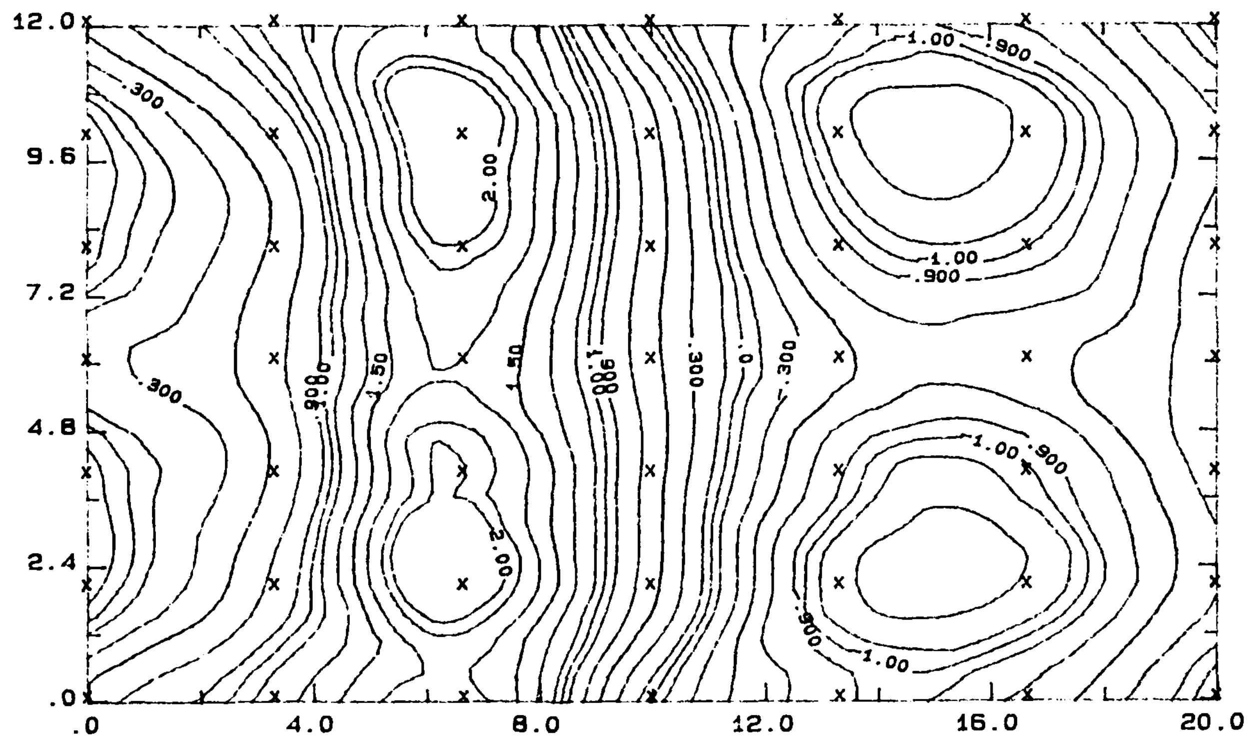
Figure 31. Contours for Moment Resultant in X for Example 2
Step 1600

hand, the results for the moment resultants show some differences in value although the behavior is similar. The moment results are very sensitive to any difference in relative displacement between joints. Figures 31 and 32 show contour plots for the moment resultants in x at similar truck locations. From these plots, it can be observed that the behavior of the moment resultant is very similar for both cases.

In Figure 26, the results of the sum of soil reactions for Examples 1, 5 and 6 are shown. These examples had pavement roughness amplitudes of zero, one fourth of an inch, and one half inch, respectively. Although the response is not exactly the same for different roughness values, it can be observed that the pattern of the variation of the sum of reactions is very similar for the three cases. Also, in general, the peaks are more or less of the same order of magnitude with few exceptions. This can be observed at the distance of four and a half and of thirteen feet.

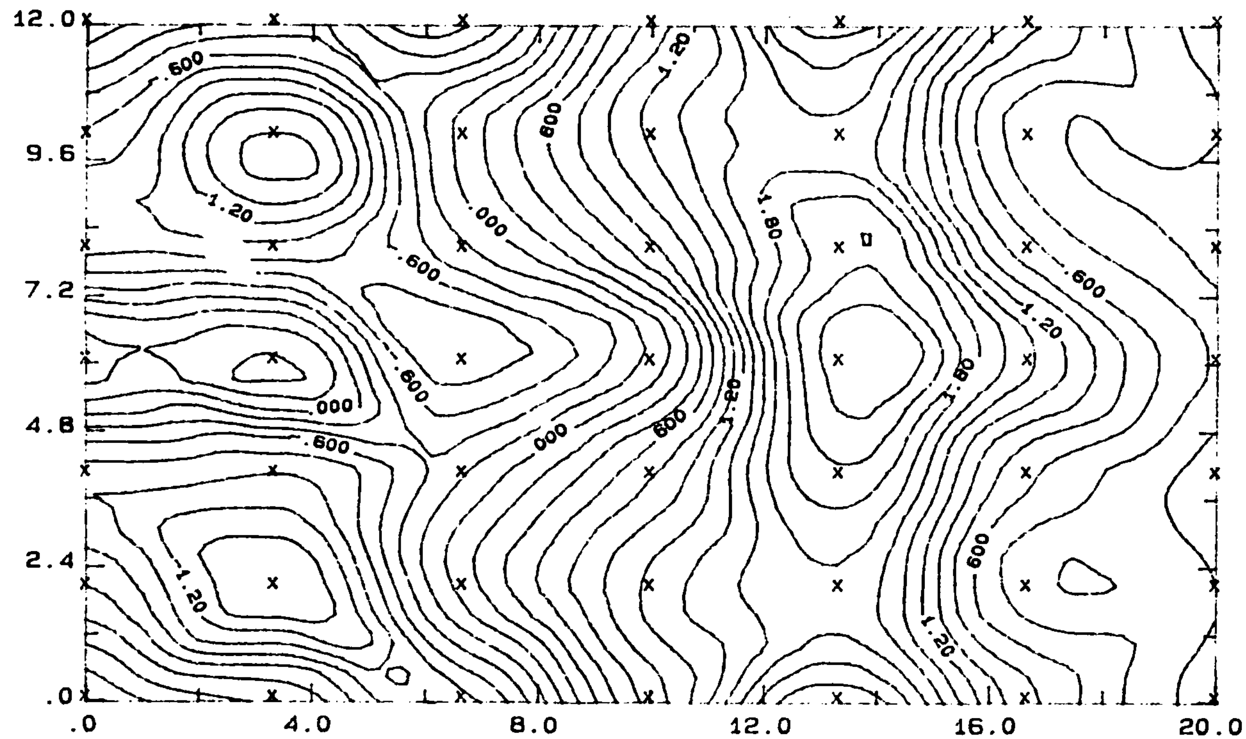
In Figures 30, 34 and 35 one can also observe that the behavior for moment resultants in x for step 1600 is also similar.

The maximum of the principal moment resultants for the interval computed are also very similar for Examples 1 and 5 and slightly smaller for Example 6. These are very significant results since they can imply that a reasonable magnitude random roughness should not increase significantly the magnitude of stresses on concrete pavements.



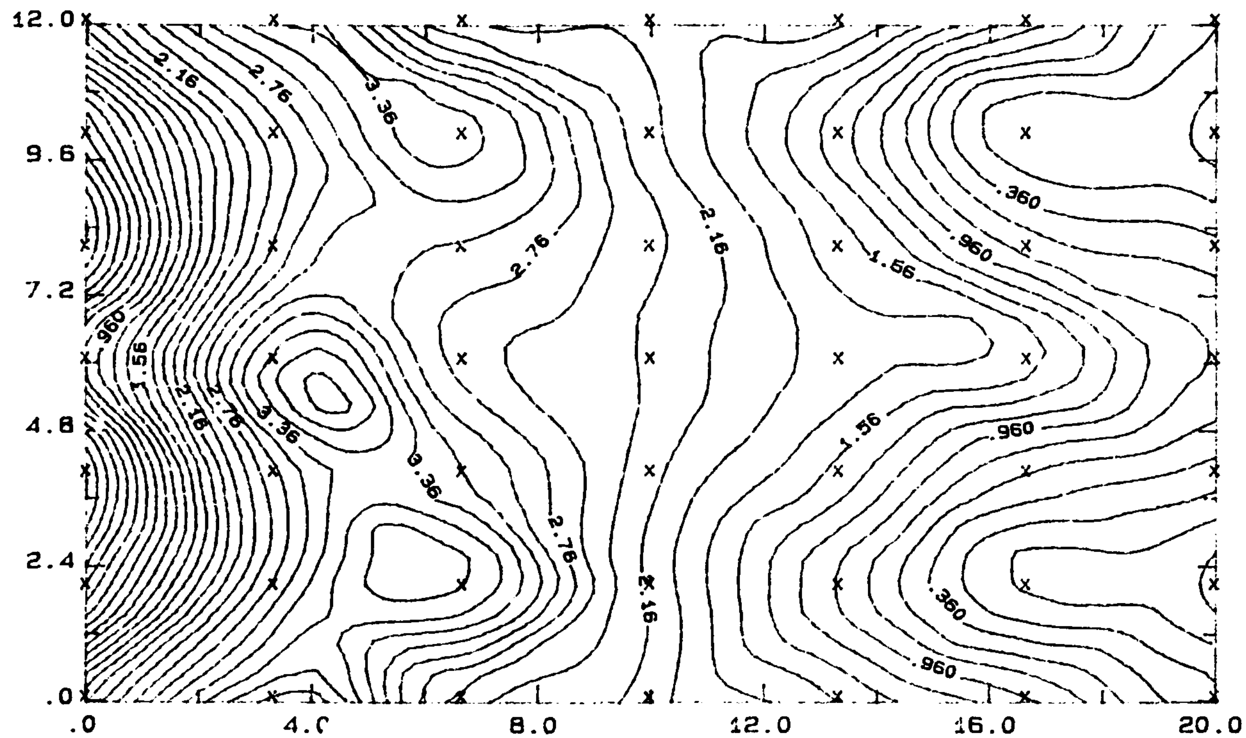

CONTOUR FROM -1.50 TO 2.90 CONTOUR INTERVAL = .50

Figure 32. Contours for Moment Resultant in X for Example 3
Step 1600



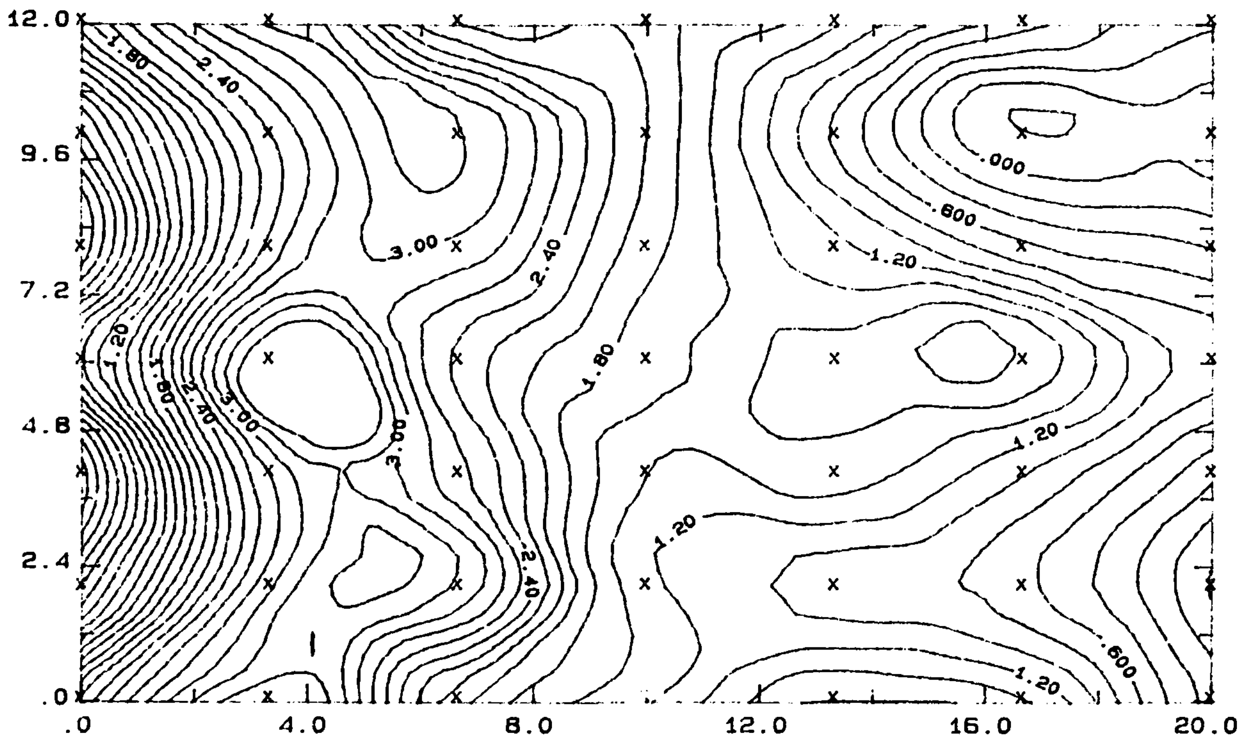

CONTOUR FROM -2.00 TO 2.40 CONTOUR INTERVAL = .20

Figure 33. Contours for Moment Resultant in X for Example 4
Step 1600




CONTOUR FROM -.64 TO 4.36 CONTOUR INTERVAL = .20

Figure 34. Contours for Moment Resultant in X for Example 5
Step 1600




CONTOUR FROM -1.00 TO 3.40 CONTOUR INTERVAL = .20

Figure 35. Contours for Moment Resultant in X for Example 6
Step 1600

In all the cases evaluated there is a considerable increase in the dynamic response of the slab after the first axle leaves the slab.

In all the cases discussed, a very large concrete crack stress was given in order to obtain the uncracked behavior of the concrete. From example 7 to 9, the concrete crack stress values were given to allow the crack formation. In examples 7 and 9, cracking didn't occur with crack stresses of -56.1 ksf and 45 ksf, respectively. For example 7, the crack stresses were lowered to 45 ksf to allow cracking of the concrete. For the same purpose, the stresses in example 9 had to be reduced to 30 ksf.

In Figure 27, the sum of soil reactions are plotted for example 1 versus example 7G. In general, due to the difference in soil characteristics (cohesive versus granular subbase), the sum of the reactions is larger for example 1. There is an exception when cracks developed causing the situation to reverse.

In Figure 28, the sum of the reaction results are plotted for examples 5 and 8. In this case, there is no significant difference in the peaks observed between one case and another. Yet, it should be observed that in example 8 the amount of cracking developed is small.

In Figure 29, the increase in the magnitude of the sum of soil reactions due to cracking of the concrete could be observed clearly since the only difference between examples 9 and 9A is that cracks develop in the later.

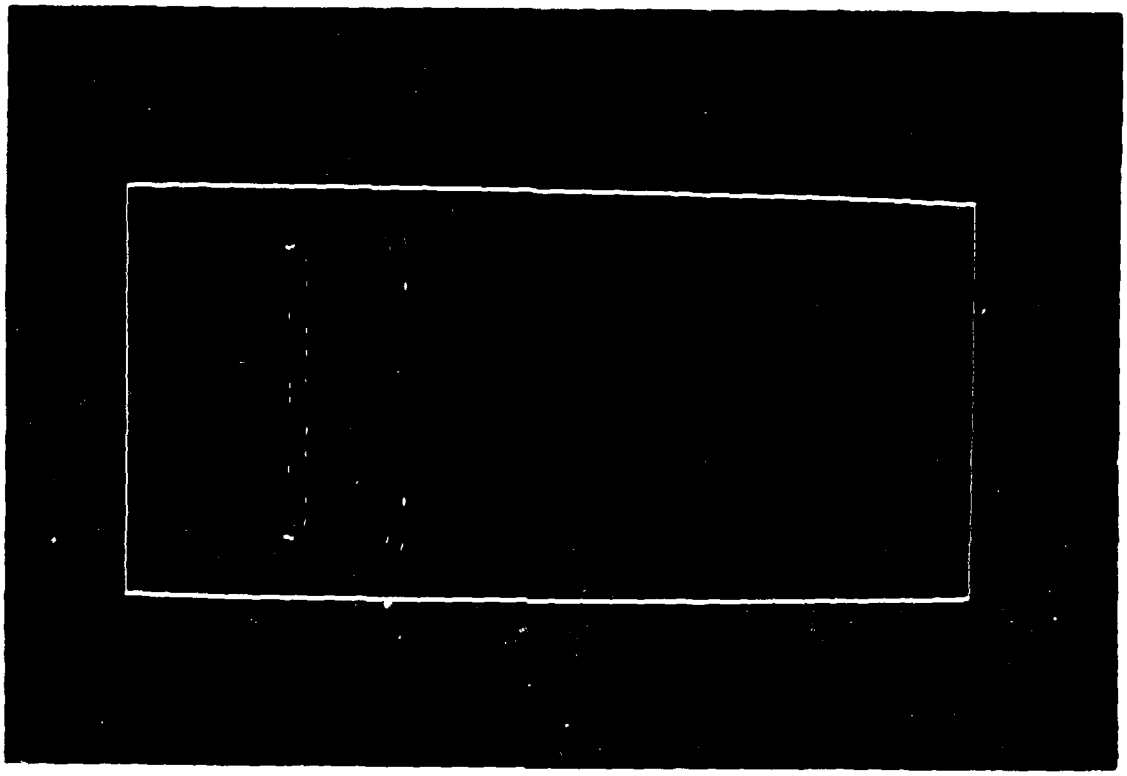
Photographies 1 to 7 show crack pictures of the different pavement examples which exhibit cracking behavior.

Example 7H starts with a transversal crack near the center of the slab when the front wheels are almost leaving the pavement. After this, other cracks develop under the wheel path and close to it. Cracks continue developing in the same manner at other locations in the pavements. The cracks closest to the tires are not transversal, but tend to take a circular pattern (see Photography 1). The top of the pavement does not crack.

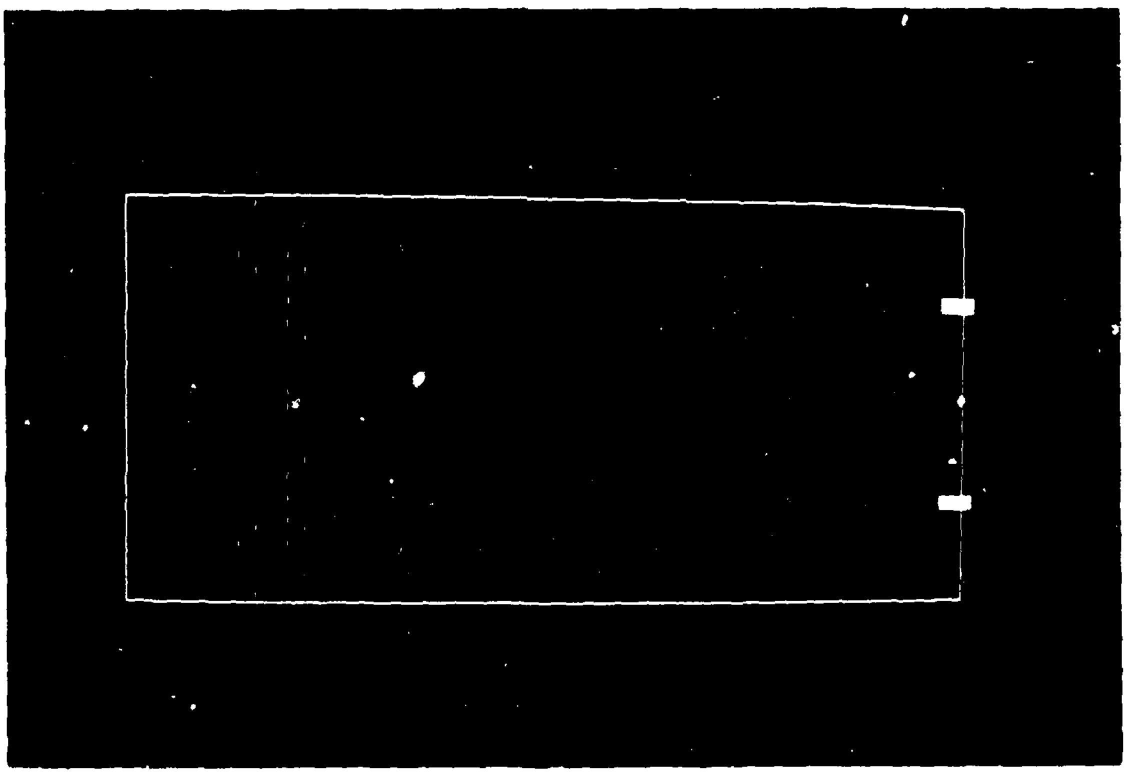
In example 7B, when the back wheels enter the pavement, some transversal cracks develop in the center of the pavement at the top surface. At the bottom, when the front wheels are near the end of the pavement, transversal cracks begin to develop at the center of the pavement. New cracks develop later near the wheels and at the edge of the pavement (see Photography 2).

In example 7G, at the bottom surface cracks start to form at the center of the pavement. This happens earlier than at example 7B. Later, other cracks appear near the wheels and close to the edge expanding towards the center along all the slab. Some cracks between the path of the wheel and the center of the slab are longitudinal. Many others form a radial pattern as can be observed from Photography 3.

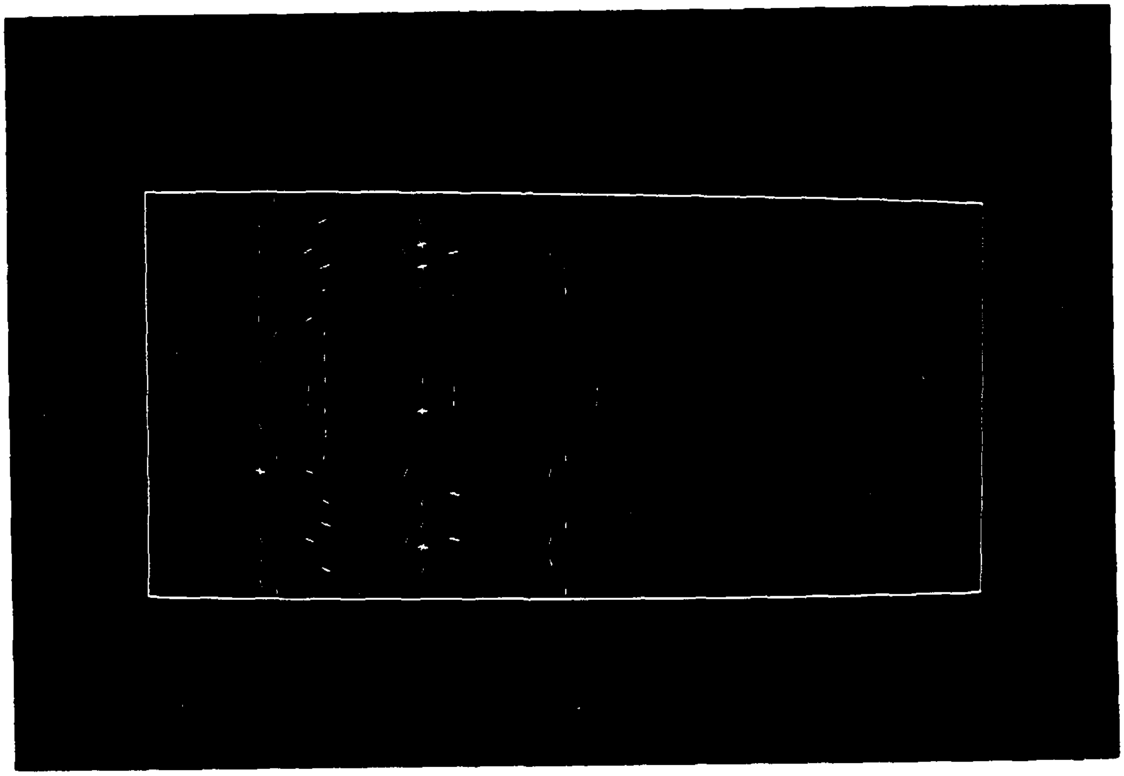
At the top surface, transversal cracks near the center of the slab start to develop when the back gear enters the slab. These cracks extend under the wheels and to the edge. As the gear advances new cracks, in a longitudinal pattern, develop between the center and the gear path (see Photography 4).



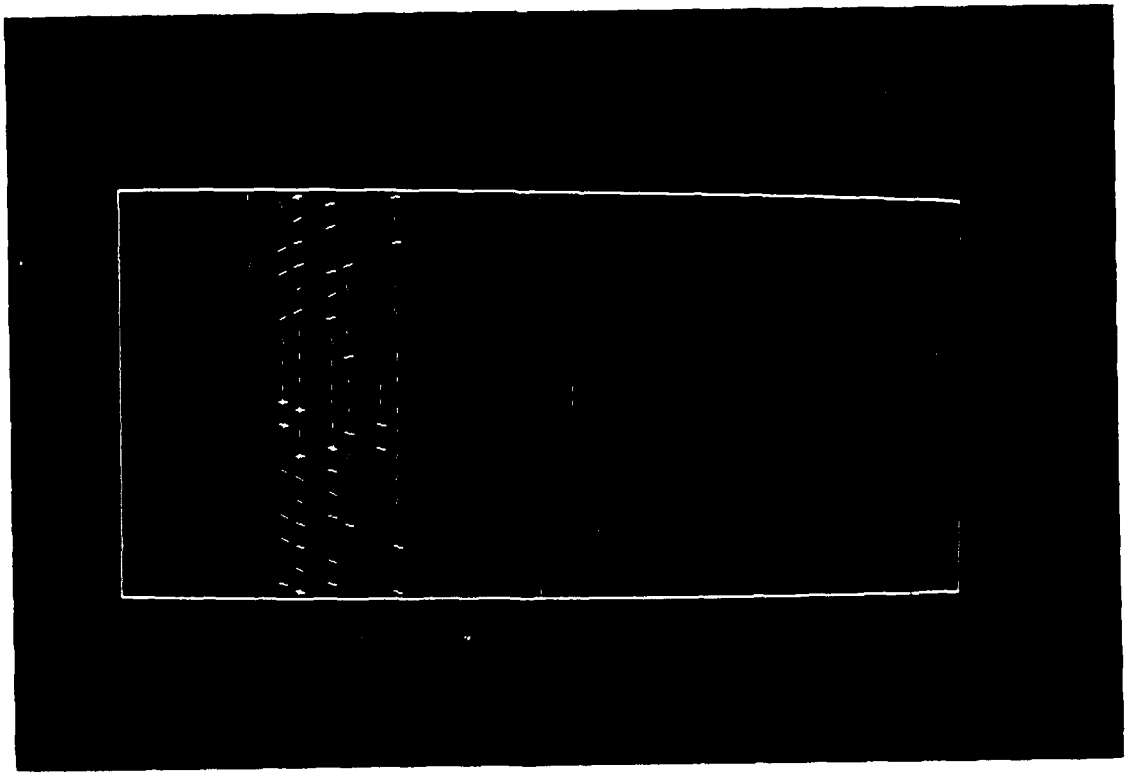
Photography 1 - Example 7H  BOTTOM



Photography 2 - Example 7B  BOTTOM



Photography 3 - Example 7G  BOTTOM



Photography 4 - Example 7G  TOP

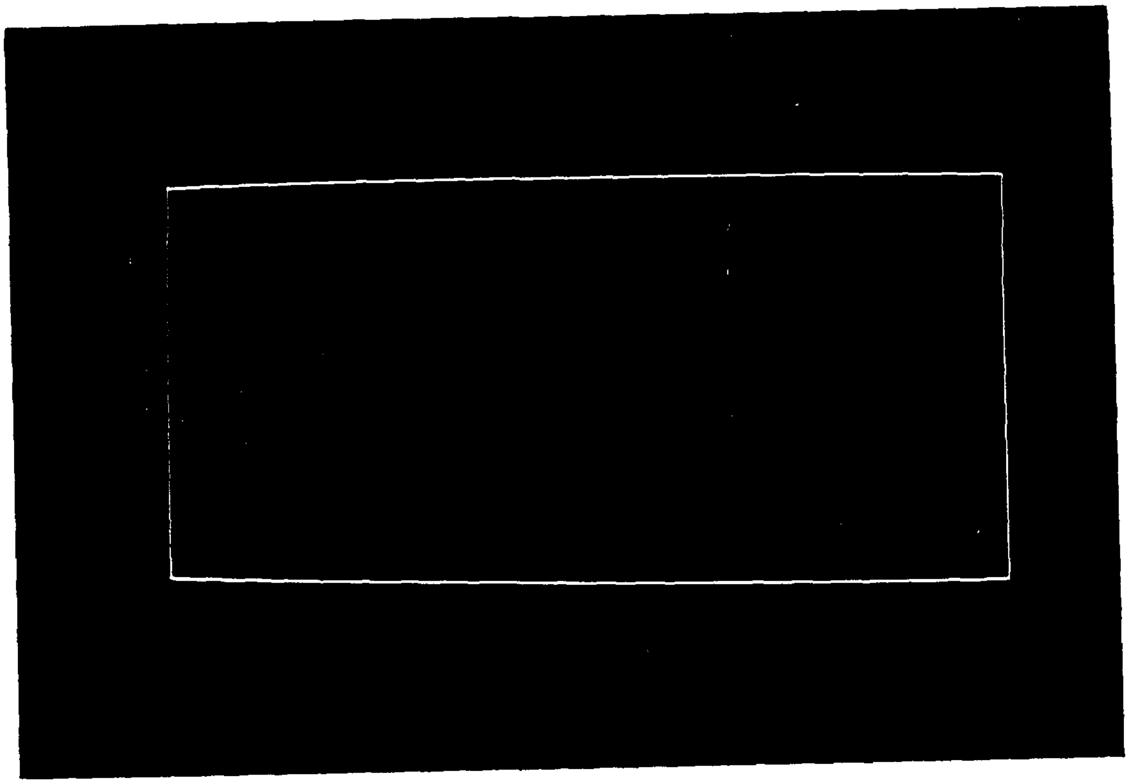
In example 8, cracks start to develop at the bottom surface when the front gear leaves the slab. These cracks form under one of the wheels and are in a transversal pattern as can be observed in Photography 5. No cracks develop at the top surface.

When the front gear in example 9A leaves the pavement, some transversal cracks develop at the bottom surface near the center. When the back gear is near the end of the slab, new cracks develop in a radial form from the tires toward the edge. Other cracks form near the center in different loops across the slab. Longitudinal cracks also develop near the edge of the slab as shown in Photography 6. At the top surface, cracks develop when the back gear is almost leaving the slab. These cracks are a few feet from the end of the pavement and in almost radial pattern (see Photography 7).

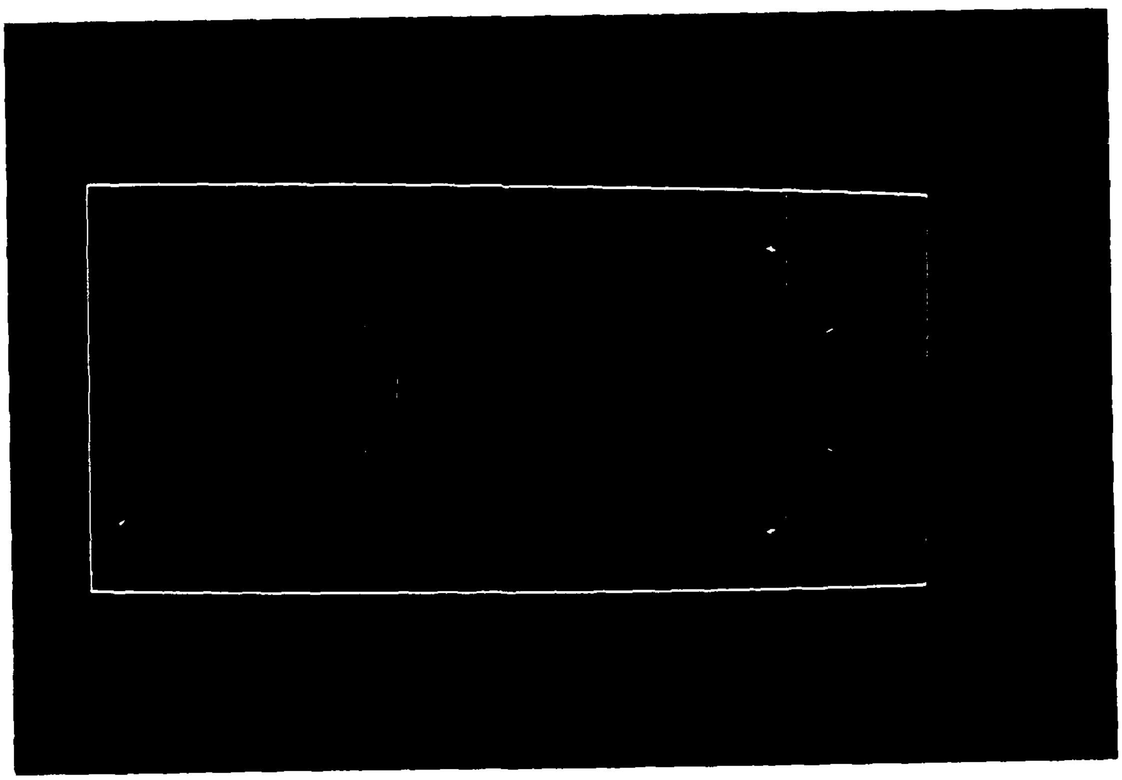
Contour plots for Examples 7 through 9 are shown respectively in Figures 37 through 39 for results of moment resultants in x at step 2000.

Figures 40 and 41 show contours for moment resultant in y at step 2000 for Examples 7 and 9, respectively. These are very similar although the moment resultants for Example 7 are larger than those for Example 9.

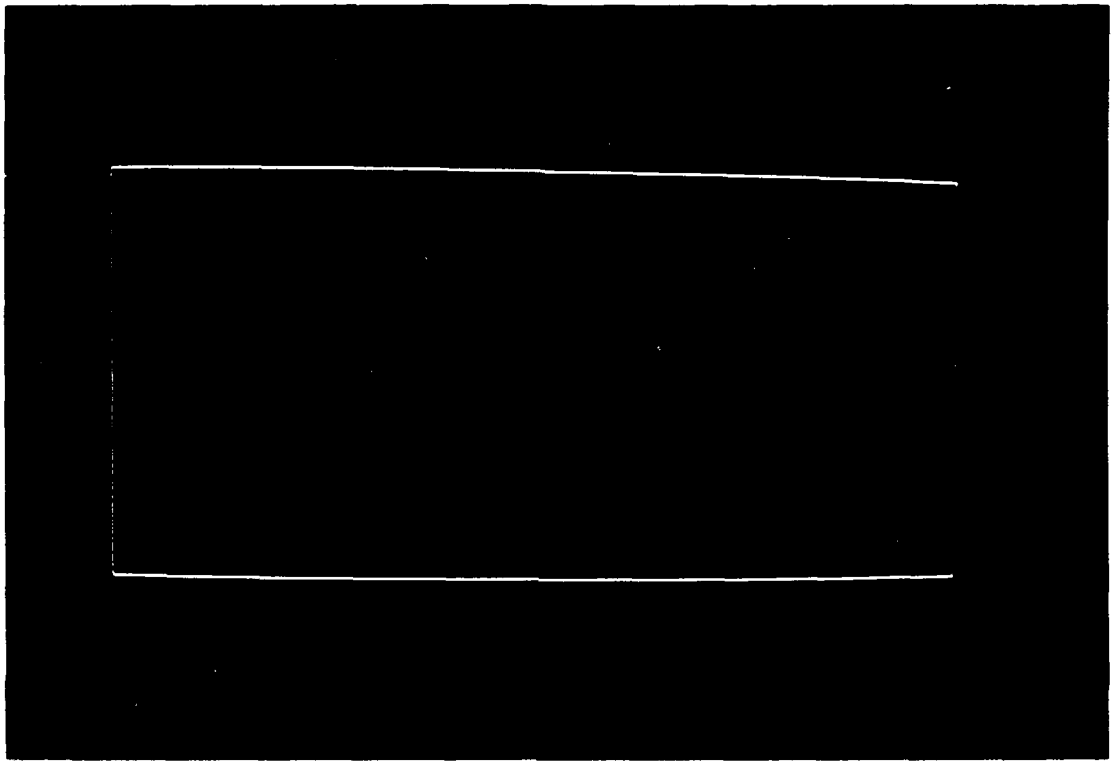
In Figures 42 and 43, contours for displacements at step 2000 for Examples 1 and 7 are shown. The effect of crack formation on the displacement for Example 7 could be observed in Figure 43. In Figures 44 and 45 soil reaction contours are shown for Examples 7 and 8 at step 1,800.



Photography 5 - Example 8 BOTTOM



Photography 6 - Example 9A BOTTOM



Photography 7 - Example 9A  TOP

There is no doubt that soil characteristics are very important in the behavior of the pavement, particularly in the formation of cracks. Yet, there is no sufficient fundamental experimental soil data that will allow to define with precision the parameters that are needed for a precise analytical representation. Therefore, until the data is available, analytical parametric studies are needed to identify the parameter that produces an overall logic behavior. Such a parametric study is out of the scope of this project.

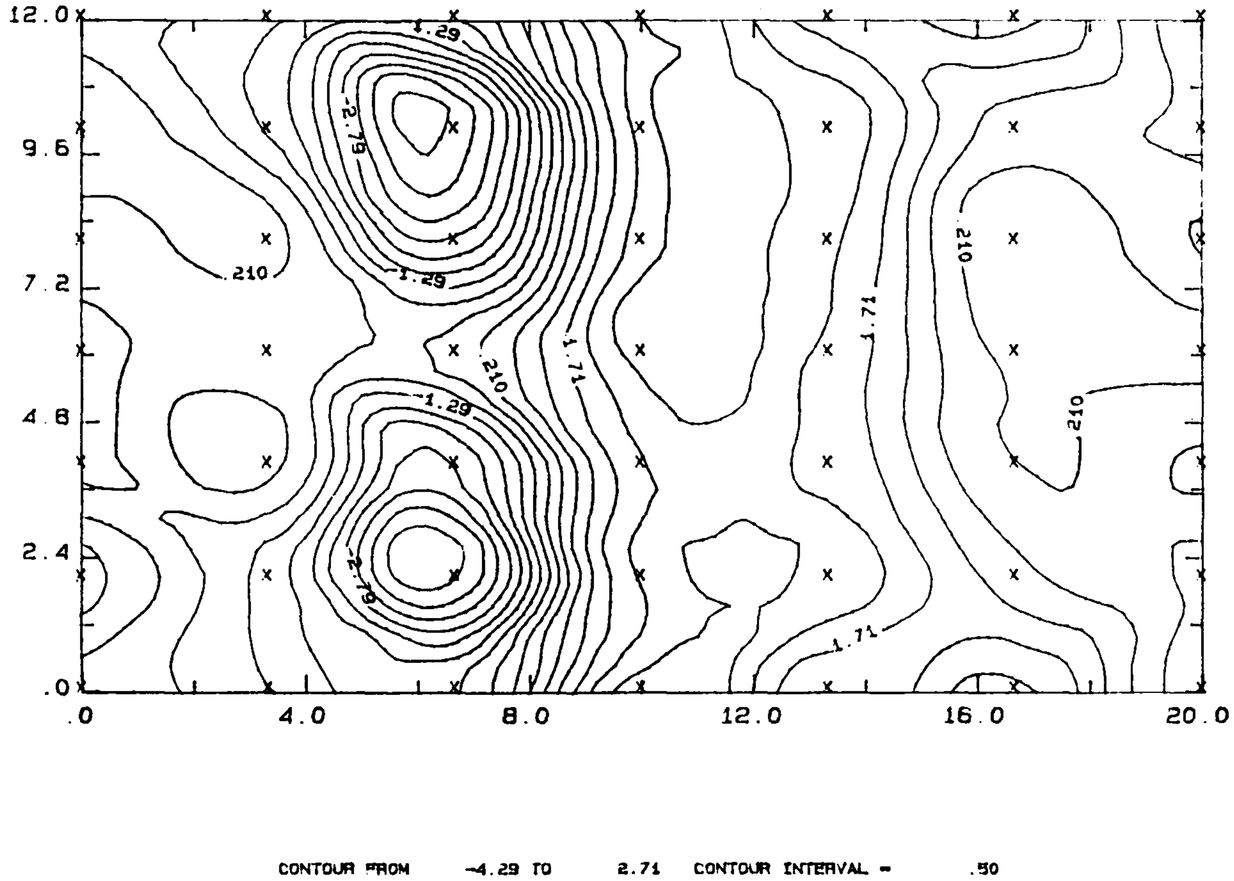
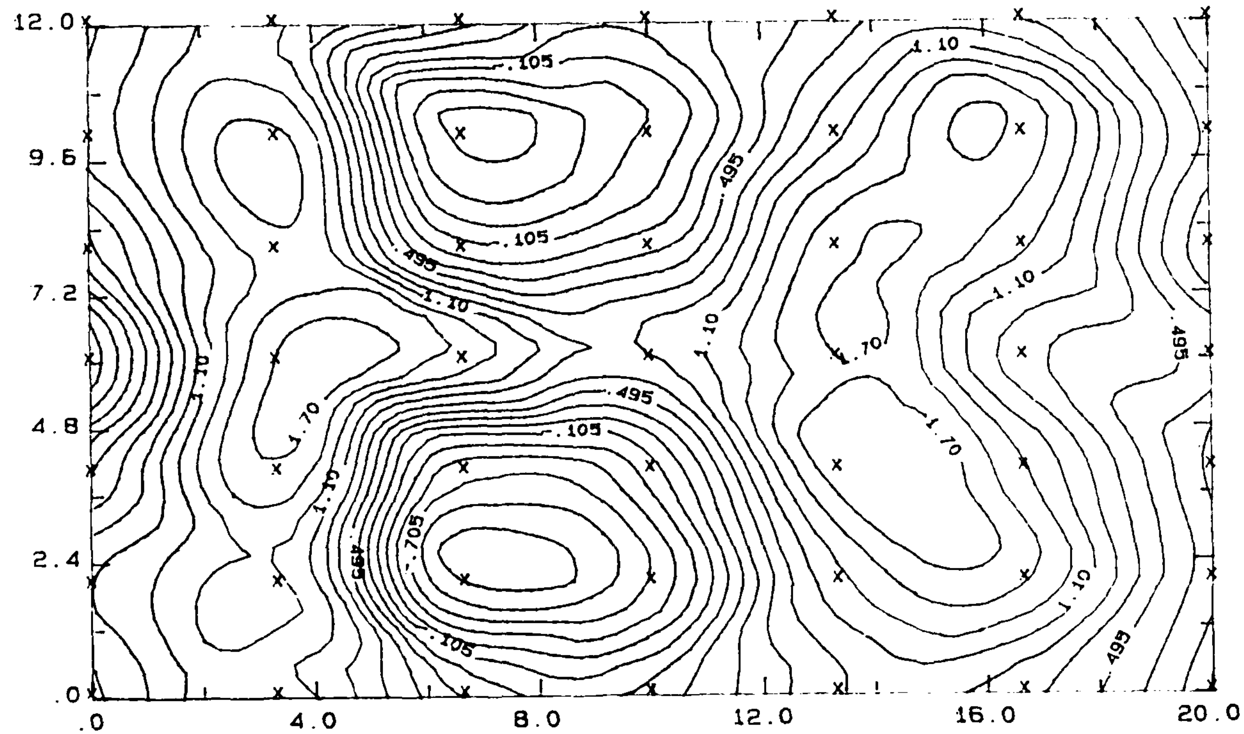
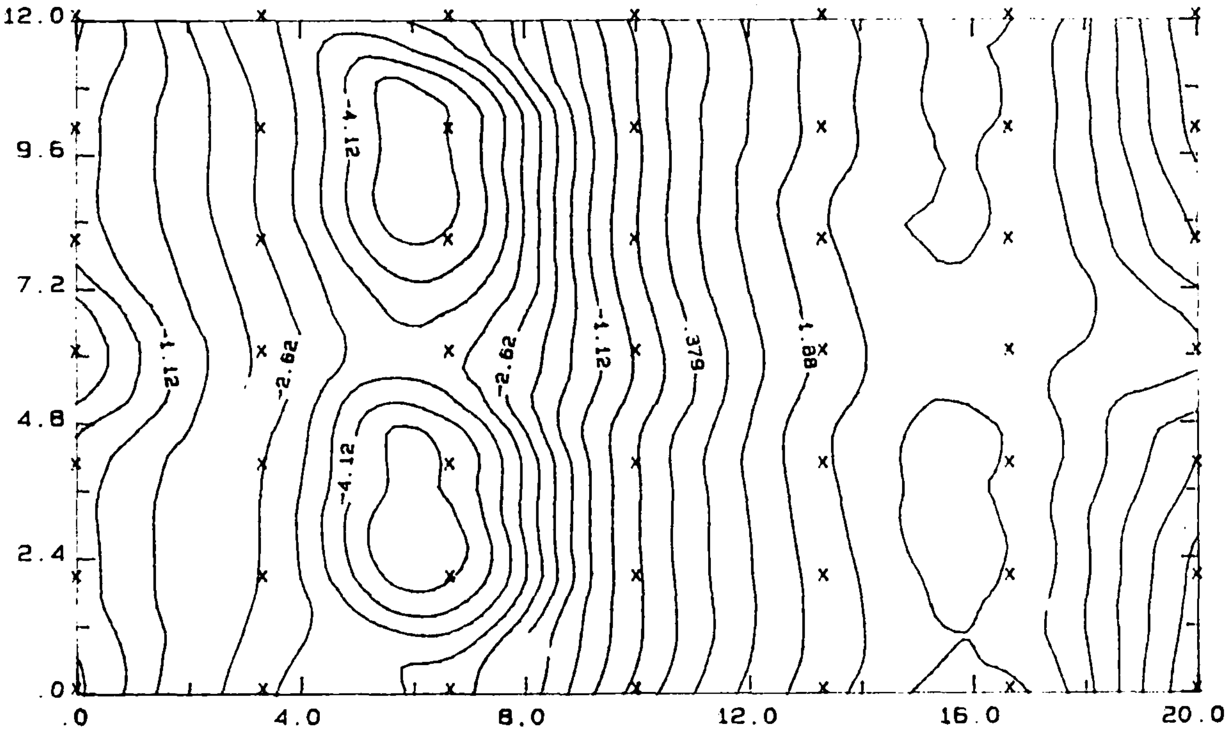



Figure 37. Contours for Moment Resultant in X for Example 7G
Step 2000



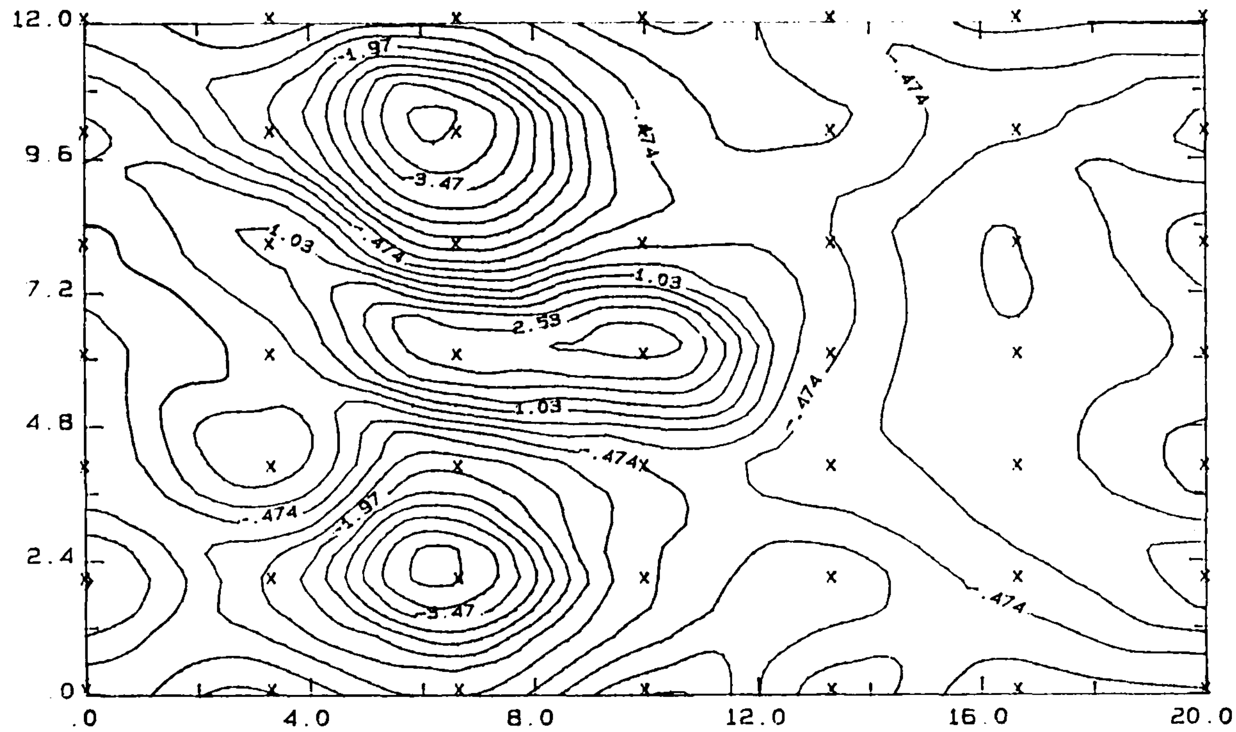

CONTOUR FROM -1.11 TO 1.70 CONTOUR INTERVAL = .20

Figure 38. Contours for Moment Resultant in X for Example 8
Step 2000



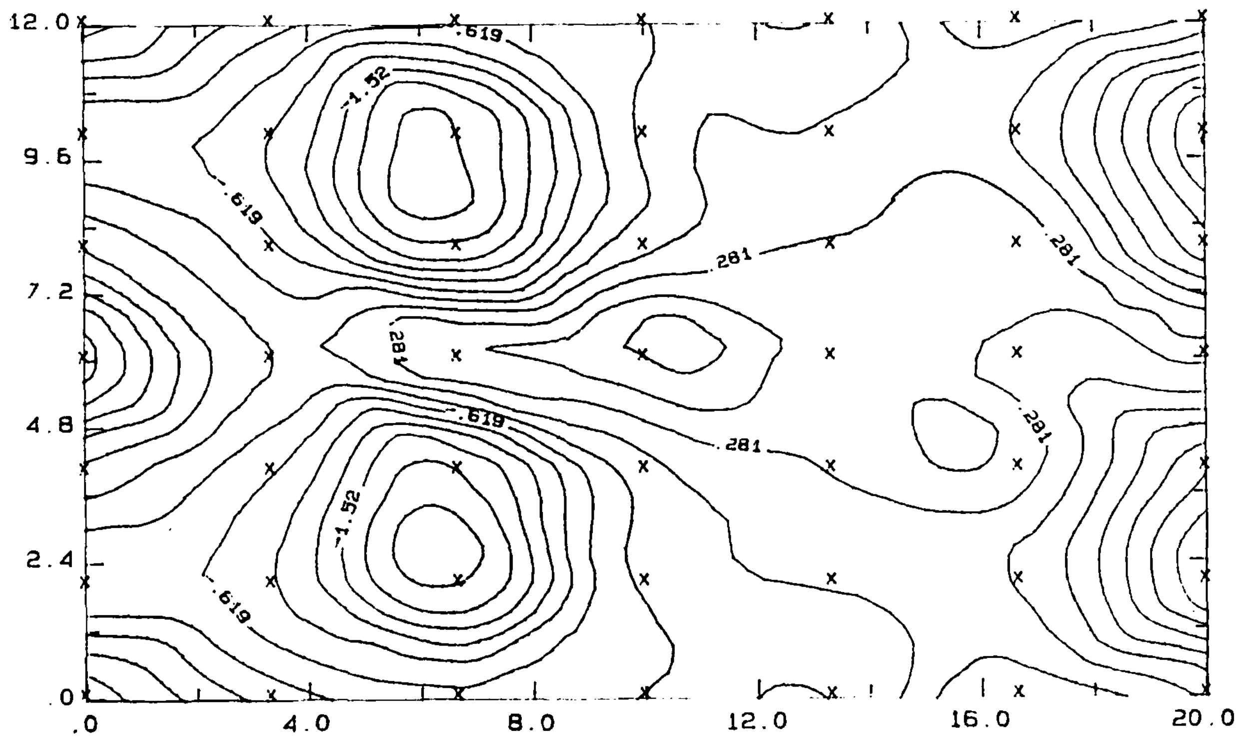

CONTOUR FROM -4.62 TO 2.88 CONTOUR INTERVAL = .50

Figure 39. Contours for Moment Resultant in X for Example 9A
Step 2000



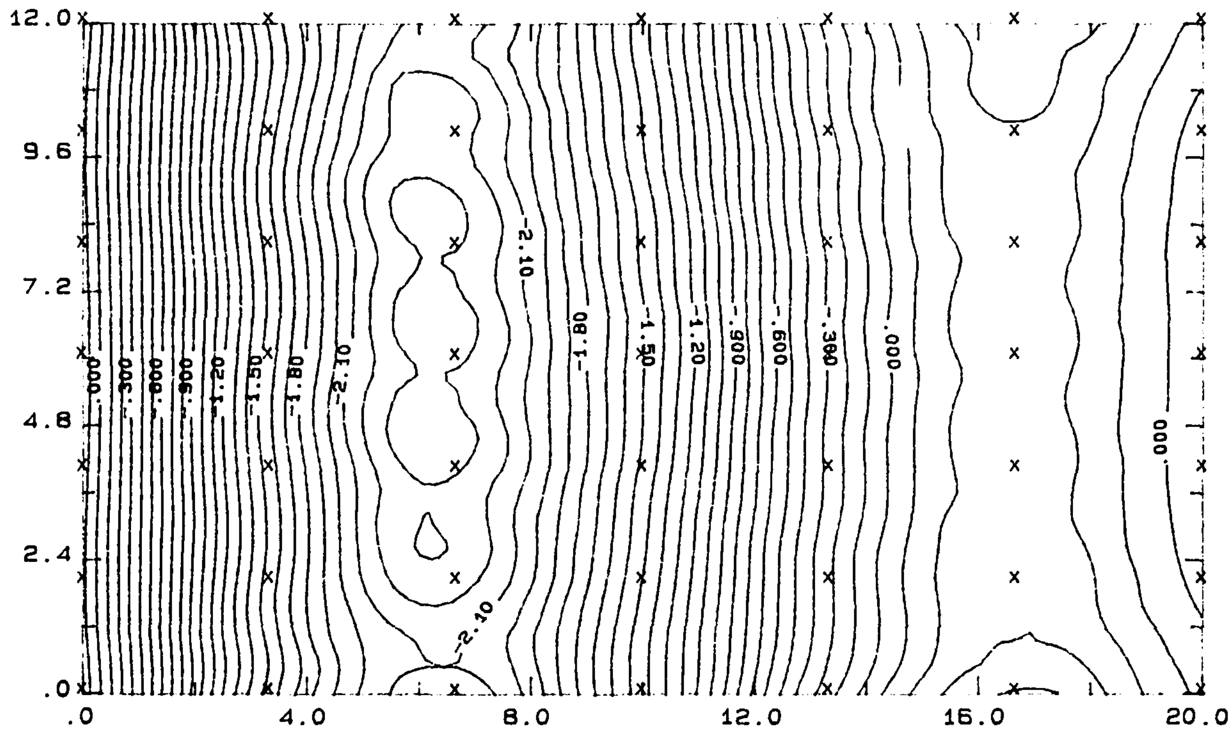

CONTOUR FROM -4.47 TO 3.03 CONTOUR INTERVAL = .50

Figure 40. Contours for Moment Resultant in Y for Example 7G
Step 2000



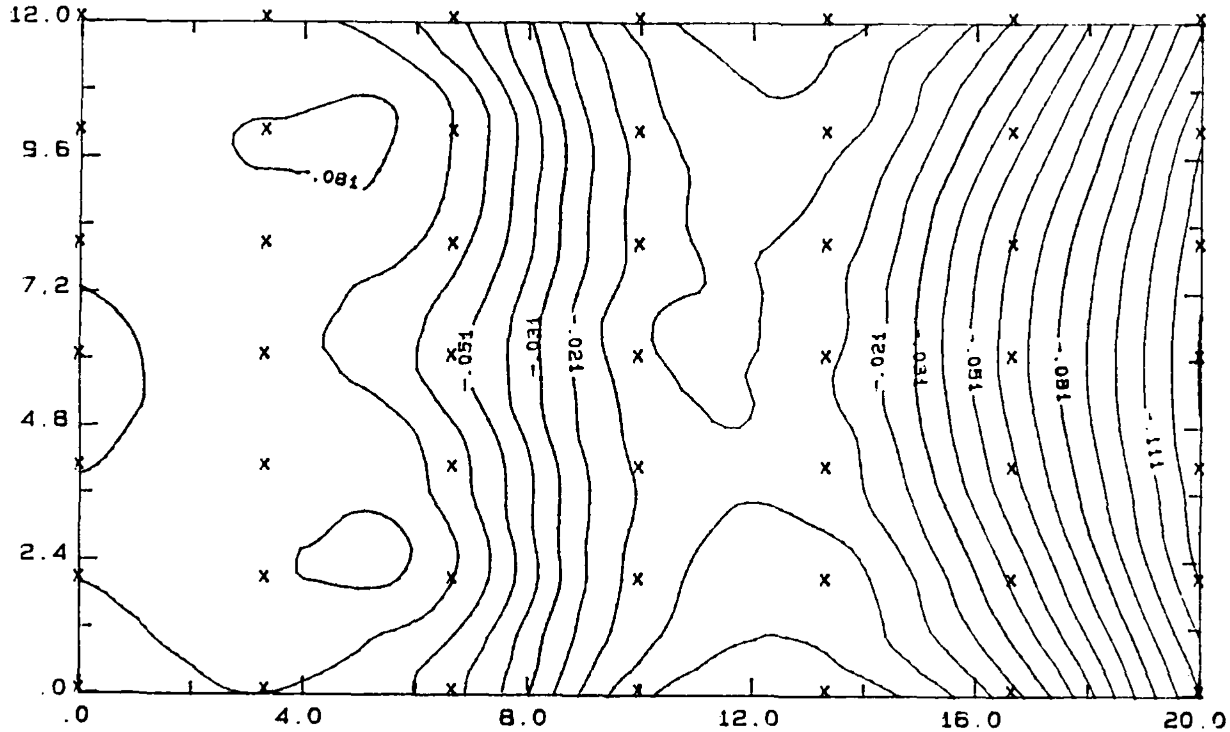

CONTOUR FROM -2.12 TO 1.48 CONTOUR INTERVAL = .30

Figure 41. Contours for Moment Resultant in Y for Example 9A
Step 2000



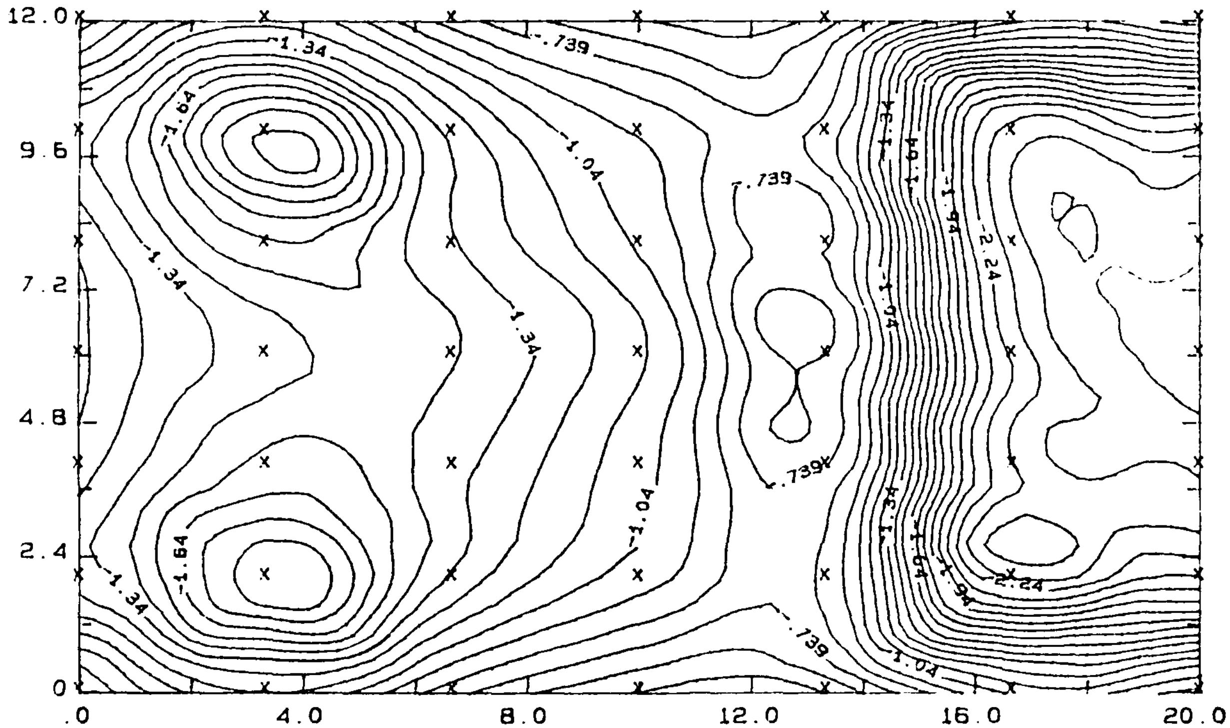

CONTOUR FROM -2.50 TO .40 CONTOUR INTERVAL = .10

Figure 42. Displacement Contours for Example 1
Step 2000 (x1000)




CONTOUR FROM -.131000 TO -.069000 CONTOUR INTERVAL = .050000

Figure 43. Displacement Contours for Example 7G
Step 2000 (x1000)




CONTOUR FROM -2.64 TO -.54 CONTOUR INTERVAL = .10

Figure 44. Soil Reaction Contours for Example 7G
Step 1800

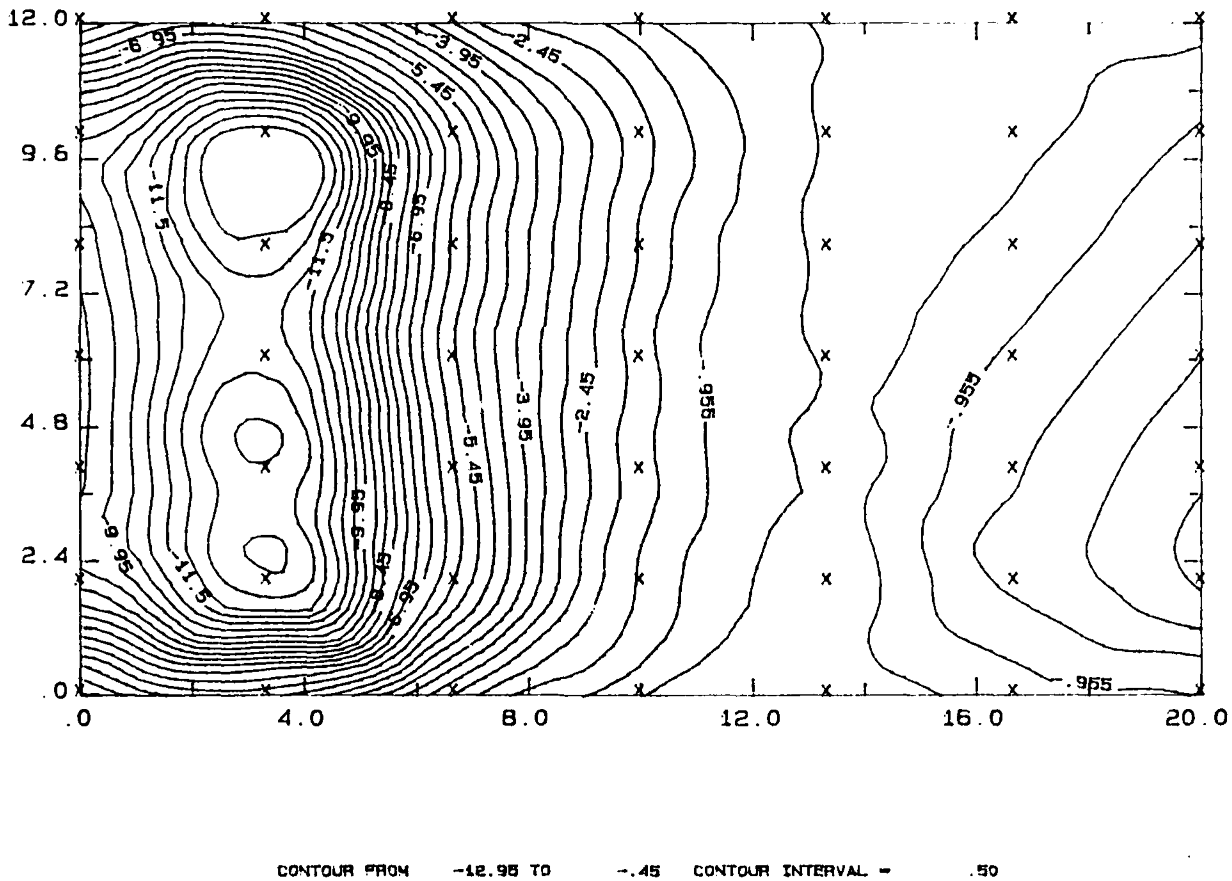



Figure 45. Soil Reaction Contours for Example 8
Step 1800

# CHAPTER 6

# CONCLUSIONS AND RECOMMENDATIONS

## 6.a Conclusions

An analytical methodology has been developed to analyze concrete pavements considering vehicle dynamic translation along the slab, soil and concrete linear behavior and roughness. The developed methodology produced very logic results representing the behavior of concrete pavements.

From the examples studied it was observed that an increase in the velocity of the vehicle does not increase the magnitude of the maximum moment resultant. On the contrary, for the cases studied, an increase in velocity decreased the maximum moment resultant. It was also observed that the introduction of a random generated roughness doesn't change significantly the behavior of the pavement.

With a time increment of 0.0002 it was possible to achieve convergence of results.

Crack formation is dependent on the subbase characteristics. Whenever soil parameters that produce a soft subbase were given, the pavement cracked transversally under the effect of the rear gear. On the contrary, when a hard subbase was defined the crack formation (if cracks occurred) was around each wheel of the rear gear and didn't propagate across the pavement.

The crack visualization program (DRACRACK) is a very usefull tool to understand the overall behavior of the pavement.

## 6.b Recommendations

One of the limitations of the developed methodology is the time consumed each time a variation in element stiffness occurred, due to a new crack formation. To improve this condition, it is recommended to modify the procedure by condensing the element stiffness matrix for each element that changes instead of condensing the total stiffness matrix. This should reduce considerable the amount of time required to obtain a solution.

Due to time limitations it was not possible to conduct a sensitivity analysis of all the parameters that affect concrete pavement behavior. It is recommended to perform additional computer runs in order to be able to define the overall pavement behavior.

Although the present study considers the level of soil stress and the soil failure effect in the computation of the modulus of subgrade reactions, it does not consider the permanent soil deformation due to soil failure. In future research studies this factor should be considered.

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# APPENDICES

# APPENDIX A

## Matrices to Compute Element Stiffness

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | +1 | $-b$ | | | $b^2$ | | | $-m'b^3$ | $-n'b^3$ |
| | | | +1 | | | $-b$ | | | |
| | | $-1$ | | | $2b$ | | | $-3m'b^2$ | $-3n'b^2$ |
| | +1 | $a$ | | $a^2$ | | | | $ma^3$ | $na^3$ |
| [C] = | | | +1 | | | $+a$ | | | |
| | | $-1$ | | $-2a$ | | | | $-3ma^2$ | $-3na^2$ |
| | 1 | | $h$ | | | | $h^2$ | | $h^3$ |
| | | | +1 | | | | $+2h$ | | $+3h^2$ |
| | | $-1$ | | | | $-h$ | | $-h^2$ | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | $-2$ | | | | $-6mx$ | $-6nx$ |
| [Ba]= | | | | | | | $-2$ | $-2x$ | $-6y$ |
| | | | | | | $-2$ | | $-4y$ | 0 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0 | 0 | 0 | $-2$ | 0 | 0 | $-6m'x$ | $-6n'x$ |
| [Bb]= | 0 | 0 | 0 | 0 | 0 | 0 | $-2$ | $-2x$ | $-6y$ |
| | 0 | 0 | 0 | 0 | 0 | $-2$ | 0 | $-4y$ | 0 |

where:

$m = [2 - (h/a)^2]/3$ $\qquad$ $n = -h/a$

$m' = [2 - (h/b)^2]/3$ $\qquad$ $n' = h/b$

| | 1 | 2 | 3 | 4 | 5 | .. | .. | (n-1)*2+4 | (N4)*2+5 | n*2+4 | n*2+5 | .. | .. | (2n-1)*2+4 | (2n-1)*2+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | $2\sum_{i=1}^{n} k_{si}$ | | | $-k_{si}$ | $-k_{si}$ | | | $-k_{sn}$ | $-k_{sn}$ | | | | | | |
| 2 | | $2\Sigma^{n} k_{si} \times A_i^s$ | | $k_{s1}XA_1$ | $K_{s1}XA_1$ | | | $k_{sr}\ XA_r$ | $K_{sr}\ XA_r$ | | | | | | |
| 3 | | | $2\Sigma^{n} K_{si}W_{Ai}$ | $-K_{s1}WA_1$ | $K_{s1}WA_1$ | | | $-K_{sr}WA_r$ | $K_{sr}\ WA_r$ | | | | | | |
| 4 | | | | $K_{s1}+K_{T1}$ | | | | | | $-K_{T1}$ | | | | | |
| 5 | | | | | $K_{s1}+K_{T1}$ | | | | | | $-K_{T1}$ | | | | |
| : | | | | | | | | | | | | | | | |
| : | | | | | | | | | | | | | | | |
| (n-1)*2+4 | | | | | | | | $K_{sn}+K_{Tn}$ | | | | | | $-K_{Tn}$ | |
| (N4)*2+5 | | | | | | | | | $K_{sn}+K_{Tn}$ | | | | | | $-K_{Tn}$ |
| n*2+4 | | | | | | | | | | $K_{T1}$ | | | | | |
| n*2+5 | | | | | | | | | | | $K_{T1}$ | | | | |
| : | | | | | | | | | | | | | | | |
| : | | | | | | | | | | | | | | | |
| (2n-1)*2+4 | | | | | | | | | | $K_{Tn}$ | | | | | |
| (2n-1)*2+5 | | | | | | | | | | | | | | | $K_{Tn}$ |

Vehicle Stiffness Matrix

# APPENDIX B

## Drivers Needs and Configuration File Requirements

To run the program GRINPAV it is necessary to use graphic drivers in the machine configuration file.

The required configuration file (CONFIG.SYS) is a follow:

```
files = 20
buffers = 20
device=\cgi\ibmpro.sys /g:printer
device=\cgi\msmouse.sys /g:input
device=\cgi\ibmega.sys /g:crt
device=\cgi\gsscgi.sys
```

Where the drivers are in subdirectory CGI.

Software license for the graphic drivers is included for a workstation.

Additional license can be purchased directly from:

Graphic Software System, Inc.
P.O. Box 4900
Benverton, Oregon 97005

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1200 00072

# APPENDIX C

## TYPICAL OUTPUT LISTING

```
DDDDDD    YY      YY NN     NN   OOOOO     PPPPPP     AAA     VV    VV
DD   DD    YY    YY  NNN    NN  O     O   PP    PP   A   A    VV    VV
DD    DD    YY  YY   NNNN   NN OO      OO PP    PP  AA   AA   VV    VV
DD    DD      YY     NN NN  NN OO      OO PP    PP  AA   AA   VV    VV
DD    DD      YY     NN  NN NN OO      OO PPPPPPP   AAAAAAA   VV    VV
DD    DD      YY     NN   NNNN OO      OO PP        AA   AA   VV    VV
DD   DD       YY     NN    NNN  O     O   PP        AA   AA    VV  VV
DDDDDD        YY     NN     NN   OOOOO    PP        AA   AA      VV
```

==========================================================================

UNIVERSITY OF PUERTO RICO
MAYAGUEZ CAMPUS
PAVEMENT BEHAVIOR PROGRAM
DYNAMIC NON-LINEAL PAVEMENT ANALYSIS
CONSIDERING CONCRETE CRACK FORMATION
AND NONLINEAR SOIL BEHAVIOR
SPONSORED BY:
AIRFORCE OFFICE OF SCIENTIFIC RESEARCH
VERSION 1.0, NOV. 1989

==========================================================================

DATE : 12-11-1989 HOUR :10: 4:41:91

---

NAME OF PROBLEM :

EXAM1-1 PAV.LISO. 20X12X1. VEL=50ft/sec I=.0002 K1=4000 K2=0.6 Ft=10000 KSF

---

NUMBER OF ELEMENTS = 72

NUMBER OF JOINTS = 49

NUMBER OF AXLES = 2

## JOINT INFORMATION

| JOINT | X (FT) | Y (FT) | BORDER CONDITION | SPRING CONSTANT (K/FT) | MASS (K-SEC**2/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0 | 250.00 | 0.01 |
| 2 | 3.333 | 0.000 | 0 | 500.00 | 0.02 |
| 3 | 6.667 | 0.000 | 0 | 500.00 | 0.02 |
| 4 | 10.000 | 0.000 | 0 | 500.00 | 0.02 |
| 5 | 13.333 | 0.000 | 0 | 500.00 | 0.02 |
| 6 | 16.667 | 0.000 | 0 | 500.00 | 0.02 |
| 7 | 20.000 | 0.000 | 0 | 250.00 | 0.01 |
| 8 | 0.000 | 2.000 | 0 | 500.00 | 0.02 |
| 9 | 3.333 | 2.000 | 0 | 1000.00 | 0.03 |
| 10 | 6.667 | 2.000 | 0 | 1000.00 | 0.03 |
| 11 | 10.000 | 2.000 | 0 | 1000.00 | 0.03 |
| 12 | 13.333 | 2.000 | 0 | 1000.00 | 0.03 |
| 13 | 16.667 | 2.000 | 0 | 1000.00 | 0.03 |
| 14 | 20.000 | 2.000 | 0 | 500.00 | 0.02 |
| 15 | 0.000 | 4.000 | 0 | 500.00 | 0.02 |
| 16 | 3.333 | 4.000 | 0 | 1000.00 | 0.03 |
| 17 | 6.667 | 4.000 | 0 | 1000.00 | 0.03 |
| 18 | 10.000 | 4.000 | 0 | 1000.00 | 0.03 |
| 19 | 13.333 | 4.000 | 0 | 1000.00 | 0.03 |
| 20 | 16.667 | 4.000 | 0 | 1000.00 | 0.03 |
| 21 | 20.000 | 4.000 | 0 | 500.00 | 0.02 |
| 22 | 0.000 | 6.000 | 0 | 500.00 | 0.02 |
| 23 | 3.333 | 6.000 | 0 | 1000.00 | 0.03 |
| 24 | 6.667 | 6.000 | 0 | 1000.00 | 0.03 |
| 25 | 10.000 | 6.000 | 0 | 1000.00 | 0.03 |
| 26 | 13.333 | 6.000 | 0 | 1000.00 | 0.03 |
| 27 | 16.667 | 6.000 | 0 | 1000.00 | 0.03 |
| 28 | 20.000 | 6.000 | 0 | 500.00 | 0.02 |
| 29 | 0.000 | 8.000 | 0 | 500.00 | 0.02 |
| 30 | 3.333 | 8.000 | 0 | 1000.00 | 0.03 |
| 31 | 6.667 | 8.000 | 0 | 1000.00 | 0.03 |
| 32 | 10.000 | 8.000 | 0 | 1000.00 | 0.03 |
| 33 | 13.333 | 8.000 | 0 | 1000.00 | 0.03 |
| 34 | 16.667 | 8.000 | 0 | 1000.00 | 0.03 |
| 35 | 20.000 | 8.000 | 0 | 500.00 | 0.02 |
| 36 | 0.000 | 10.000 | 0 | 500.00 | 0.02 |
| 37 | 3.333 | 10.000 | 0 | 1000.00 | 0.03 |
| 38 | 6.667 | 10.000 | 0 | 1000.00 | 0.03 |
| 39 | 10.000 | 10.000 | 0 | 1000.00 | 0.03 |
| 40 | 13.333 | 10.000 | 0 | 1000.00 | 0.03 |
| 41 | 16.667 | 10.000 | 0 | 1000.00 | 0.03 |
| 42 | 20.000 | 10.000 | 0 | 500.00 | 0.02 |
| 43 | 0.000 | 12.000 | 0 | 250.00 | 0.01 |
| 44 | 3.333 | 12.000 | 0 | 500.00 | 0.02 |
| 45 | 6.667 | 12.000 | 0 | 500.00 | 0.02 |
| 46 | 10.000 | 12.000 | 0 | 500.00 | 0.02 |
| 47 | 13.333 | 12.000 | 0 | 500.00 | 0.02 |
| 48 | 16.667 | 12.000 | 0 | 500.00 | 0.02 |
| 49 | 20.000 | 12.000 | 0 | 250.00 | 0.01 |

## ELEMENT INFORMATION

| ELEMENTS | JOINT DFINITION FROM | TO | TO | THICKNESS (FT) | YOUNG MODULE (KSF) | POISSON |
|---|---|---|---|---|---|---|
| 1 | 9 | 1 | 2 | 1.000 | 0.5184E+06 | 0.160 |
| 2 | 10 | 2 | 3 | 1.000 | 0.5184E+06 | 0.160 |
| 3 | 11 | 3 | 4 | 1.000 | 0.5184E+06 | 0.160 |
| 4 | 12 | 4 | 5 | 1.000 | 0.5184E+06 | 0.160 |
| 5 | 13 | 5 | 6 | 1.000 | 0.5184E+06 | 0.160 |
| 6 | 14 | 6 | 7 | 1.000 | 0.5184E+06 | 0.160 |
| 7 | 1 | 9 | 8 | 1.000 | 0.5184E+06 | 0.160 |
| 8 | 2 | 10 | 9 | 1.000 | 0.5184E+06 | 0.160 |
| 9 | 3 | 11 | 10 | 1.000 | 0.5184E+06 | 0.160 |
| 10 | 4 | 12 | 11 | 1.000 | 0.5184E+06 | 0.160 |
| 11 | 5 | 13 | 12 | 1.000 | 0.5184E+06 | 0.160 |
| 12 | 6 | 14 | 13 | 1.000 | 0.5184E+06 | 0.160 |
| 13 | 16 | 8 | 9 | 1.000 | 0.5184E+06 | 0.160 |
| 14 | 17 | 9 | 10 | 1.000 | 0.5184E+06 | 0.160 |
| 15 | 18 | 10 | 11 | 1.000 | 0.5184E+06 | 0.160 |
| 16 | 19 | 11 | 12 | 1.000 | 0.5184E+06 | 0.160 |
| 17 | 20 | 12 | 13 | 1.000 | 0.5184E+06 | 0.160 |
| 18 | 21 | 13 | 14 | 1.000 | 0.5184E+06 | 0.160 |
| 19 | 8 | 16 | 15 | 1.000 | 0.5184E+06 | 0.160 |
| 20 | 9 | 17 | 16 | 1.000 | 0.5184E+06 | 0.160 |
| 21 | 10 | 18 | 17 | 1.000 | 0.5184E+06 | 0.160 |
| 22 | 11 | 19 | 18 | 1.000 | 0.5184E+06 | 0.160 |
| 23 | 12 | 20 | 19 | 1.000 | 0.5184E+06 | 0.160 |
| 24 | 13 | 21 | 20 | 1.000 | 0.5184E+06 | 0.160 |
| 25 | 23 | 15 | 16 | 1.000 | 0.5184E+06 | 0.160 |
| 26 | 24 | 16 | 17 | 1.000 | 0.5184E+06 | 0.160 |
| 27 | 25 | 17 | 18 | 1.000 | 0.5184E+06 | 0.160 |
| 28 | 26 | 18 | 19 | 1.000 | 0.5184E+06 | 0.160 |
| 29 | 27 | 19 | 20 | 1.000 | 0.5184E+06 | 0.160 |
| 30 | 28 | 20 | 21 | 1.000 | 0.5184E+06 | 0.160 |
| 31 | 15 | 23 | 22 | 1.000 | 0.5184E+06 | 0.160 |
| 32 | 16 | 24 | 23 | 1.000 | 0.5184E+06 | 0.160 |
| 33 | 17 | 25 | 24 | 1.000 | 0.5184E+06 | 0.160 |
| 34 | 18 | 26 | 25 | 1.000 | 0.5184E+06 | 0.160 |
| 35 | 19 | 27 | 26 | 1.000 | 0.5184E+06 | 0.160 |
| 36 | 20 | 28 | 27 | 1.000 | 0.5184E+06 | 0.160 |
| 37 | 23 | 29 | 22 | 1.000 | 0.5184E+06 | 0.160 |
| 38 | 24 | 30 | 23 | 1.000 | 0.5184E+06 | 0.160 |
| 39 | 25 | 31 | 24 | 1.000 | 0.5184E+06 | 0.160 |
| 40 | 26 | 32 | 25 | 1.000 | 0.5184E+06 | 0.160 |
| 41 | 27 | 33 | 26 | 1.000 | 0.5184E+06 | 0.160 |
| 42 | 28 | 34 | 27 | 1.000 | 0.5184E+06 | 0.160 |
| 43 | 29 | 23 | 30 | 1.000 | 0.5184E+06 | 0.160 |
| 44 | 30 | 24 | 31 | 1.000 | 0.5184E+06 | 0.160 |
| 45 | 31 | 25 | 32 | 1.000 | 0.5184E+06 | 0.160 |
| 46 | 32 | 26 | 33 | 1.000 | 0.5184E+06 | 0.160 |
| 47 | 33 | 27 | 34 | 1.000 | 0.5184E+06 | 0.160 |
| 48 | 34 | 28 | 35 | 1.000 | 0.5184E+06 | 0.160 |
| 49 | 30 | 36 | 29 | 1.000 | 0.5184E+06 | 0.160 |
| 50 | 31 | 37 | 30 | 1.000 | 0.5184E+06 | 0.160 |
| 51 | 32 | 38 | 31 | 1.000 | 0.5184E+06 | 0.160 |
| 52 | 33 | 39 | 32 | 1.000 | 0.5184E+06 | 0.160 |
| 53 | 34 | 40 | 33 | 1.000 | 0.5184E+06 | 0.160 |
| 54 | 35 | 41 | 34 | 1.000 | 0.5184E+06 | 0.160 |
| 55 | 36 | 30 | 37 | 1.000 | 0.5184E+06 | 0.160 |
| 56 | 37 | 31 | 38 | 1.000 | 0.5184E+06 | 0.160 |
| 57 | 38 | 32 | 39 | 1.000 | 0.5184E+06 | 0.160 |
| 58 | 39 | 33 | 40 | 1.000 | 0.5184E+06 | 0.160 |

ELEMENT INFORMATION

| ELEMENTS | JOINT DFINITION FROM | TO | TO | THICKNESS (FT) | YOUNG MODULE (KSF) | POISSON |
|---|---|---|---|---|---|---|
| 59 | 40 | 34 | 41 | 1.000 | 0.5184E+06 | 0.160 |
| 60 | 41 | 35 | 42 | 1.000 | 0.5184E+06 | 0.160 |
| 61 | 37 | 43 | 36 | 1.000 | 0.5184E+06 | 0.160 |
| 62 | 38 | 44 | 37 | 1.000 | 0.5184E+06 | 0.160 |
| 63 | 39 | 45 | 38 | 1.000 | 0.5184E+06 | 0.160 |
| 64 | 40 | 46 | 39 | 1.000 | 0.5184E+06 | 0.160 |
| 65 | 41 | 47 | 40 | 1.000 | 0.5184E+06 | 0.160 |
| 66 | 42 | 48 | 41 | 1.000 | 0.5184E+06 | 0.160 |
| 67 | 43 | 37 | 44 | 1.000 | 0.5184E+06 | 0.160 |
| 68 | 44 | 38 | 45 | 1.000 | 0.5184E+06 | 0.160 |
| 69 | 45 | 39 | 46 | 1.000 | 0.5184E+06 | 0.160 |
| 70 | 46 | 40 | 47 | 1.000 | 0.5184E+06 | 0.160 |
| 71 | 47 | 41 | 48 | 1.000 | 0.5184E+06 | 0.160 |
| 72 | 48 | 42 | 49 | 1.000 | 0.5184E+06 | 0.160 |

## ANALYSIS CHARACTERISTICS

INCREMENTAL PROCEDURE
TIME INCREMENT = 1.99999995E-04 SEG

## VEHICLE CHARACTERISTICS

| | | |
|---|---|---|
| NUMBER OF AXLES | = | 2 |
| VEHICLE MASS | = | 1.565 |
| ROTATIONAL MASSX | = | 16.000 |
| ROTATIONAL MASSY | = | 42.000 |
| FRACTION OF MASS AT BODY LEVEL | = | 0.900 |
| DISTANCE BETWEEN "X" AXIS AND VEHICLE CENTER OF GRAVITY | = | 6.000(FT) |
| VEHICLE VELOCITY | = | 50.000(FT/SEG) |

| AXLE NUM | DISTANCE TO CENTROID (FT) | WHEEL SEPARATION (FT) | AXLE FORCE (KIPS) | TIRE STIFFNESS (K/FT) | VEHICLE STIFFNESS (K/FT) | TIRE MASS (K-SEC^2/FT) |
|---|---|---|---|---|---|---|
| 1 | 12.00 | 6.00 | -8.00 | 70.00 | 12.00 | 0.01 |
| 2 | -2.00 | 6.00 | -48.00 | 140.00 | 72.00 | 0.07 |

## SOIL PROPERTIES

| | | |
|---|---|---|
| SOIL COEFFICIENT ONE | = | 4000.000 |
| SOIL COEFFICIENT TWO | = | 0.600 |
| SOIL POSSION RATIO | = | 0.300 |
| SOIL DEPTH | = | 8.000(FT) |
| SOIL ELEVATION FACTOR | = | 6.000 |
| SOIL FRICTION ANGLE | = | 0.000(DEGREE) |
| SOIL COHESION | = | 0.015(PSI) |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-1 .SX PAGE 1

INTERVAL = 200 TIME = 0.040 DISTANCE = 2.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.246 | -0.136 | -0.077 |
| 2 | 3.333 | 0.000 | 0.554 | 0.090 | -0.104 |
| 3 | 6.667 | 0.000 | 0.364 | 0.022 | -0.064 |
| 4 | 10.000 | 0.000 | 0.201 | -0.001 | -0.025 |
| 5 | 13.333 | 0.000 | 0.103 | -0.001 | -0.021 |
| 6 | 16.667 | 0.000 | 0.058 | 0.009 | -0.015 |
| 7 | 20.000 | 0.000 | 0.019 | 0.034 | -0.007 |
| 8 | 0.000 | 2.000 | 0.069 | -0.358 | -0.030 |
| 9 | 3.333 | 2.000 | 0.424 | -0.069 | -0.064 |
| 10 | 6.667 | 2.000 | 0.486 | 0.067 | -0.057 |
| 11 | 10.000 | 2.000 | 0.213 | -0.033 | -0.032 |
| 12 | 13.333 | 2.000 | 0.047 | -0.115 | -0.026 |
| 13 | 16.667 | 2.000 | -0.013 | -0.135 | -0.013 |
| 14 | 20.000 | 2.000 | -0.021 | -0.126 | -0.003 |
| 15 | 0.000 | 4.000 | -0.030 | -0.376 | 0.039 |
| 16 | 3.333 | 4.000 | 0.382 | -0.133 | -0.006 |
| 17 | 6.667 | 4.000 | 0.450 | -0.013 | -0.024 |
| 18 | 10.000 | 4.000 | 0.225 | -0.006 | -0.029 |
| 19 | 13.333 | 4.000 | 0.105 | 0.010 | -0.027 |
| 20 | 16.667 | 4.000 | 0.059 | 0.015 | -0.012 |
| 21 | 20.000 | 4.000 | 0.031 | -0.032 | -0.006 |
| 22 | 0.000 | 6.000 | 0.074 | 0.253 | 0.000 |
| 23 | 3.333 | 6.000 | 0.446 | 0.099 | 0.000 |
| 24 | 6.667 | 6.000 | 0.409 | -0.090 | 0.000 |
| 25 | 10.000 | 6.000 | 0.236 | -0.067 | 0.000 |
| 26 | 13.333 | 6.000 | 0.153 | 0.058 | 0.000 |
| 27 | 16.667 | 6.000 | 0.134 | 0.143 | 0.000 |
| 28 | 20.000 | 6.000 | 0.088 | 0.132 | 0.000 |
| 29 | 0.000 | 8.000 | -0.030 | -0.376 | -0.039 |
| 30 | 3.333 | 8.000 | 0.382 | -0.133 | 0.006 |
| 31 | 6.667 | 8.000 | 0.450 | -0.013 | 0.024 |
| 32 | 10.000 | 8.000 | 0.225 | -0.006 | 0.029 |
| 33 | 13.333 | 8.000 | 0.105 | 0.010 | 0.027 |
| 34 | 16.667 | 8.000 | 0.059 | 0.015 | 0.012 |
| 35 | 20.000 | 8.000 | 0.031 | -0.032 | 0.006 |
| 36 | 0.000 | 10.000 | 0.069 | -0.358 | 0.030 |
| 37 | 3.333 | 10.000 | 0.424 | -0.069 | 0.064 |
| 38 | 6.667 | 10.000 | 0.486 | 0.067 | 0.057 |
| 39 | 10.000 | 10.000 | 0.213 | -0.033 | 0.032 |
| 40 | 13.333 | 10.000 | 0.047 | -0.115 | 0.026 |
| 41 | 16.667 | 10.000 | -0.013 | -0.135 | 0.013 |
| 42 | 20.000 | 10.000 | -0.021 | -0.126 | 0.003 |
| 43 | 0.000 | 12.000 | 0.246 | -0.136 | 0.077 |
| 44 | 3.333 | 12.000 | 0.554 | 0.090 | 0.104 |
| 45 | 6.667 | 12.000 | 0.364 | 0.022 | 0.064 |
| 46 | 10.000 | 12.000 | 0.201 | -0.001 | 0.025 |
| 47 | 13.333 | 12.000 | 0.103 | -0.001 | 0.021 |
| 48 | 16.667 | 12.000 | 0.058 | 0.009 | 0.015 |
| 49 | 20.000 | 12.000 | 0.019 | 0.034 | 0.007 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-1 .SX PAGE 2

INTERVAL = 400 TIME = 0.080 DISTANCE = 4.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.198 | 0.090 | 0.082 |
| 2 | 3.333 | 0.000 | -0.367 | -0.181 | 0.091 |
| 3 | 6.667 | 0.000 | 0.193 | -0.009 | 0.013 |
| 4 | 10.000 | 0.000 | 0.326 | 0.070 | -0.039 |
| 5 | 13.333 | 0.000 | 0.139 | 0.039 | -0.039 |
| 6 | 16.667 | 0.000 | -0.028 | -0.031 | -0.016 |
| 7 | 20.000 | 0.000 | 0.000 | 0.012 | -0.009 |
| 8 | 0.000 | 2.000 | -0.060 | 0.182 | 0.036 |
| 9 | 3.333 | 2.000 | -0.386 | -0.122 | 0.055 |
| 10 | 6.667 | 2.000 | 0.013 | -0.091 | 0.009 |
| 11 | 10.000 | 2.000 | 0.269 | -0.006 | -0.019 |
| 12 | 13.333 | 2.000 | 0.205 | 0.064 | -0.025 |
| 13 | 16.667 | 2.000 | 0.031 | 0.034 | -0.022 |
| 14 | 20.000 | 2.000 | -0.027 | -0.035 | -0.020 |
| 15 | 0.000 | 4.000 | -0.081 | 0.080 | -0.005 |
| 16 | 3.333 | 4.000 | -0.434 | -0.165 | 0.019 |
| 17 | 6.667 | 4.000 | 0.053 | 0.013 | -0.004 |
| 18 | 10.000 | 4.000 | 0.289 | 0.033 | 0.002 |
| 19 | 13.333 | 4.000 | 0.159 | 0.014 | -0.002 |
| 20 | 16.667 | 4.000 | 0.010 | 0.030 | -0.020 |
| 21 | 20.000 | 4.000 | 0.031 | 0.077 | -0.034 |
| 22 | 0.000 | 6.000 | 0.002 | 0.051 | 0.000 |
| 23 | 3.333 | 6.000 | -0.367 | -0.048 | 0.000 |
| 24 | 6.667 | 6.000 | 0.069 | 0.198 | 0.000 |
| 25 | 10.000 | 6.000 | 0.337 | 0.141 | 0.000 |
| 26 | 13.333 | 6.000 | 0.151 | -0.025 | 0.000 |
| 27 | 16.667 | 6.000 | -0.008 | -0.030 | 0.000 |
| 28 | 20.000 | 6.000 | 0.027 | 0.086 | 0.000 |
| 29 | 0.000 | 8.000 | -0.081 | 0.080 | 0.005 |
| 30 | 3.333 | 8.000 | -0.434 | -0.165 | -0.019 |
| 31 | 6.667 | 8.000 | 0.053 | 0.013 | 0.004 |
| 32 | 10.000 | 8.000 | 0.289 | 0.033 | -0.002 |
| 33 | 13.333 | 8.000 | 0.159 | 0.014 | 0.002 |
| 34 | 16.667 | 8.000 | 0.010 | 0.030 | 0.020 |
| 35 | 20.000 | 8.000 | 0.031 | 0.077 | 0.034 |
| 36 | 0.000 | 10.000 | -0.060 | 0.182 | -0.036 |
| 37 | 3.333 | 10.000 | -0.386 | -0.122 | -0.055 |
| 38 | 6.667 | 10.000 | 0.013 | -0.091 | -0.009 |
| 39 | 10.000 | 10.000 | 0.269 | -0.006 | 0.019 |
| 40 | 13.333 | 10.000 | 0.205 | 0.064 | 0.025 |
| 41 | 16.667 | 10.000 | 0.031 | 0.034 | 0.022 |
| 42 | 20.000 | 10.000 | -0.027 | -0.035 | 0.020 |
| 43 | 0.000 | 12.000 | -0.198 | 0.090 | -0.081 |
| 44 | 3.333 | 12.000 | -0.367 | -0.181 | -0.091 |
| 45 | 6.667 | 12.000 | 0.193 | -0.009 | -0.013 |
| 46 | 10.000 | 12.000 | 0.326 | 0.070 | 0.039 |
| 47 | 13.333 | 12.000 | 0.139 | 0.039 | 0.039 |
| 48 | 16.667 | 12.000 | -0.028 | -0.031 | 0.016 |
| 49 | 20.000 | 12.000 | 0.000 | 0.012 | 0.009 |

UNIVERSITY OF PUERTO RICO     FILE NAME = EXAM1-2 .SX     PAGE 1

INTERVAL = 100     TIME = 0.020     DISTANCE = 2.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.019 | -0.047 | -0.016 |
| 2 | 3.333 | 0.000 | 0.127 | -0.001 | -0.046 |
| 3 | 6.667 | 0.000 | 0.186 | 0.054 | -0.065 |
| 4 | 10.000 | 0.000 | -0.013 | 0.001 | -0.024 |
| 5 | 13.333 | 0.000 | -0.092 | -0.012 | -0.006 |
| 6 | 16.667 | 0.000 | -0.052 | -0.016 | -0.002 |
| 7 | 20.000 | 0.000 | 0.010 | 0.030 | 0.004 |
| 8 | 0.000 | 2.000 | 0.019 | -0.087 | -0.018 |
| 9 | 3.333 | 2.000 | 0.012 | -0.099 | -0.031 |
| 10 | 6.667 | 2.000 | 0.219 | 0.055 | -0.052 |
| 11 | 10.000 | 2.000 | 0.068 | 0.026 | -0.030 |
| 12 | 13.333 | 2.000 | -0.146 | -0.087 | -0.010 |
| 13 | 16.667 | 2.000 | -0.075 | -0.050 | -0.003 |
| 14 | 20.000 | 2.000 | -0.038 | -0.057 | 0.002 |
| 15 | 0.000 | 4.000 | -0.029 | -0.153 | -0.006 |
| 16 | 3.333 | 4.000 | -0.016 | -0.153 | -0.008 |
| 17 | 6.667 | 4.000 | 0.196 | 0.012 | -0.023 |
| 18 | 10.000 | 4.000 | 0.064 | 0.022 | -0.025 |
| 19 | 13.333 | 4.000 | -0.100 | -0.015 | -0.014 |
| 20 | 16.667 | 4.000 | -0.057 | 0.012 | -0.003 |
| 21 | 20.000 | 4.000 | 0.009 | 0.032 | -0.004 |
| 22 | 0.000 | 6.000 | -0.002 | -0.004 | 0.000 |
| 23 | 3.333 | 6.000 | 0.071 | -0.001 | 0.000 |
| 24 | 6.667 | 6.000 | 0.157 | -0.028 | 0.000 |
| 25 | 10.000 | 6.000 | 0.043 | -0.066 | 0.000 |
| 26 | 13.333 | 6.000 | -0.020 | 0.068 | 0.000 |
| 27 | 16.667 | 6.000 | -0.025 | 0.104 | 0.000 |
| 28 | 20.000 | 6.000 | 0.009 | 0.094 | 0.000 |
| 29 | 0.000 | 8.000 | -0.029 | -0.153 | 0.006 |
| 30 | 3.333 | 8.000 | -0.016 | -0.153 | 0.008 |
| 31 | 6.667 | 8.000 | 0.196 | 0.012 | 0.023 |
| 32 | 10.000 | 8.000 | 0.064 | 0.022 | 0.025 |
| 33 | 13.333 | 8.000 | -0.100 | -0.015 | 0.014 |
| 34 | 16.667 | 8.000 | -0.057 | 0.012 | 0.003 |
| 35 | 20.000 | 8.000 | 0.009 | 0.032 | 0.004 |
| 36 | 0.000 | 10.000 | 0.019 | -0.087 | 0.018 |
| 37 | 3.333 | 10.000 | 0.012 | -0.099 | 0.031 |
| 38 | 6.667 | 10.000 | 0.219 | 0.055 | 0.052 |
| 39 | 10.000 | 10.000 | 0.068 | 0.026 | 0.031 |
| 40 | 13.333 | 10.000 | -0.146 | -0.087 | 0.010 |
| 41 | 16.667 | 10.000 | -0.075 | -0.050 | 0.003 |
| 42 | 20.000 | 10.000 | -0.038 | -0.057 | -0.002 |
| 43 | 0.000 | 12.000 | 0.019 | -0.047 | 0.016 |
| 44 | 3.333 | 12.000 | 0.127 | -0.001 | 0.046 |
| 45 | 6.667 | 12.000 | 0.186 | 0.054 | 0.065 |
| 46 | 10.000 | 12.000 | -0.013 | 0.001 | 0.024 |
| 47 | 13.333 | 12.000 | -0.092 | -0.012 | 0.006 |
| 48 | 16.667 | 12.000 | -0.052 | -0.016 | 0.002 |
| 49 | 20.000 | 12.000 | 0.010 | 0.030 | -0.004 |

INTERVAL = 200 TIME = 0.040 DISTANCE = 4.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.098 | -0.081 | -0.050 |
| 2 | 3.333 | 0.000 | 0.256 | 0.067 | -0.081 |
| 3 | 6.667 | 0.000 | 0.132 | -0.006 | -0.059 |
| 4 | 10.000 | 0.000 | 0.121 | -0.013 | -0.020 |
| 5 | 13.333 | 0.000 | 0.104 | -0.008 | -0.009 |
| 6 | 16.667 | 0.000 | 0.090 | 0.017 | -0.007 |
| 7 | 20.000 | 0.000 | 0.016 | 0.028 | 0.002 |
| 8 | 0.000 | 2.000 | 0.022 | -0.226 | -0.029 |
| 9 | 3.333 | 2.000 | 0.106 | -0.125 | -0.052 |
| 10 | 6.667 | 2.000 | 0.208 | 0.015 | -0.053 |
| 11 | 10.000 | 2.000 | 0.130 | -0.019 | -0.030 |
| 12 | 13.333 | 2.000 | 0.044 | -0.102 | -0.017 |
| 13 | 16.667 | 2.000 | 0.015 | -0.124 | -0.005 |
| 14 | 20.000 | 2.000 | -0.014 | -0.130 | 0.004 |
| 15 | 0.000 | 4.000 | -0.034 | -0.237 | 0.004 |
| 16 | 3.333 | 4.000 | 0.079 | -0.177 | -0.012 |
| 17 | 6.667 | 4.000 | 0.168 | -0.060 | -0.021 |
| 18 | 10.000 | 4.000 | 0.142 | 0.009 | -0.027 |
| 19 | 13.333 | 4.000 | 0.108 | 0.028 | -0.023 |
| 20 | 16.667 | 4.000 | 0.086 | 0.028 | -0.008 |
| 21 | 20.000 | 4.000 | 0.038 | -0.036 | -0.001 |
| 22 | 0.000 | 6.000 | 0.014 | 0.069 | 0.000 |
| 23 | 3.333 | 6.000 | 0.200 | 0.053 | 0.000 |
| 24 | 6.667 | 6.000 | 0.148 | -0.065 | 0.000 |
| 25 | 10.000 | 6.000 | 0.129 | -0.028 | 0.000 |
| 26 | 13.333 | 6.000 | 0.150 | 0.087 | 0.000 |
| 27 | 16.667 | 6.000 | 0.161 | 0.161 | 0.000 |
| 28 | 20.000 | 6.000 | 0.098 | 0.129 | 0.000 |
| 29 | 0.000 | 8.000 | -0.034 | -0.237 | -0.004 |
| 30 | 3.333 | 8.000 | 0.079 | -0.177 | 0.012 |
| 31 | 6.667 | 8.000 | 0.168 | -0.060 | 0.021 |
| 32 | 10.000 | 8.000 | 0.142 | 0.009 | 0.027 |
| 33 | 13.333 | 8.000 | 0.108 | 0.028 | 0.023 |
| 34 | 16.667 | 8.000 | 0.086 | 0.028 | 0.008 |
| 35 | 20.000 | 8.000 | 0.038 | -0.036 | 0.001 |
| 36 | 0.000 | 10.000 | 0.022 | -0.226 | 0.029 |
| 37 | 3.333 | 10.000 | 0.106 | -0.125 | 0.052 |
| 38 | 6.667 | 10.000 | 0.208 | 0.015 | 0.053 |
| 39 | 10.000 | 10.000 | 0.130 | -0.019 | 0.030 |
| 40 | 13.333 | 10.000 | 0.044 | -0.102 | 0.017 |
| 41 | 16.667 | 10.000 | 0.015 | -0.124 | 0.005 |
| 42 | 20.000 | 10.000 | -0.014 | -0.130 | -0.004 |
| 43 | 0.000 | 12.000 | 0.098 | -0.081 | 0.050 |
| 44 | 3.333 | 12.000 | 0.256 | 0.067 | 0.081 |
| 45 | 6.667 | 12.000 | 0.132 | -0.006 | 0.059 |
| 46 | 10.000 | 12.000 | 0.121 | -0.013 | 0.020 |
| 47 | 13.333 | 12.000 | 0.104 | -0.008 | 0.009 |
| 48 | 16.667 | 12.000 | 0.090 | 0.017 | 0.007 |
| 49 | 20.000 | 12.000 | 0.016 | 0.028 | -0.002 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-3 .SX PAGE 1

INTERVAL = 200 TIME = 0.020 DISTANCE = 2.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.067 | 0.006 | -0.056 |
| 2 | 3.333 | 0.000 | 0.096 | -0.012 | -0.054 |
| 3 | 6.667 | 0.000 | 0.189 | 0.046 | -0.057 |
| 4 | 10.000 | 0.000 | 0.006 | 0.007 | -0.025 |
| 5 | 13.333 | 0.000 | -0.092 | -0.019 | -0.004 |
| 6 | 16.667 | 0.000 | -0.039 | -0.010 | -0.002 |
| 7 | 20.000 | 0.000 | 0.011 | 0.030 | -0.001 |
| 8 | 0.000 | 2.000 | -0.043 | -0.195 | -0.021 |
| 9 | 3.333 | 2.000 | 0.032 | -0.085 | -0.032 |
| 10 | 6.667 | 2.000 | 0.219 | 0.063 | -0.047 |
| 11 | 10.000 | 2.000 | 0.061 | 0.010 | -0.031 |
| 12 | 13.333 | 2.000 | -0.132 | -0.090 | -0.011 |
| 13 | 16.667 | 2.000 | -0.090 | -0.076 | -0.002 |
| 14 | 20.000 | 2.000 | -0.033 | -0.059 | 0.000 |
| 15 | 0.000 | 4.000 | -0.034 | -0.132 | 0.010 |
| 16 | 3.333 | 4.000 | 0.002 | -0.132 | -0.001 |
| 17 | 6.667 | 4.000 | 0.189 | 0.012 | -0.024 |
| 18 | 10.000 | 4.000 | 0.071 | 0.023 | -0.027 |
| 19 | 13.333 | 4.000 | -0.079 | 0.001 | -0.015 |
| 20 | 16.667 | 4.000 | -0.051 | 0.019 | -0.004 |
| 21 | 20.000 | 4.000 | 0.004 | 0.016 | -0.004 |
| 22 | 0.000 | 6.000 | 0.024 | 0.039 | 0.000 |
| 23 | 3.333 | 6.000 | 0.019 | -0.054 | 0.000 |
| 24 | 6.667 | 6.000 | 0.144 | -0.041 | 0.000 |
| 25 | 10.000 | 6.000 | 0.062 | -0.054 | 0.000 |
| 26 | 13.333 | 6.000 | -0.031 | 0.043 | 0.000 |
| 27 | 16.667 | 6.000 | -0.018 | 0.108 | 0.000 |
| 28 | 20.000 | 6.000 | 0.019 | 0.111 | 0.000 |
| 29 | 0.000 | 8.000 | -0.034 | -0.132 | -0.010 |
| 30 | 3.333 | 8.000 | 0.002 | -0.132 | 0.001 |
| 31 | 6.667 | 8.000 | 0.189 | 0.012 | 0.024 |
| 32 | 10.000 | 8.000 | 0.071 | 0.023 | 0.027 |
| 33 | 13.333 | 8.000 | -0.079 | 0.001 | 0.015 |
| 34 | 16.667 | 8.000 | -0.051 | 0.019 | 0.004 |
| 35 | 20.000 | 8.000 | 0.004 | 0.016 | 0.004 |
| 36 | 0.000 | 10.000 | -0.043 | -0.194 | 0.021 |
| 37 | 3.333 | 10.000 | 0.032 | -0.085 | 0.032 |
| 38 | 6.667 | 10.000 | 0.219 | 0.063 | 0.047 |
| 39 | 10.000 | 10.000 | 0.061 | 0.010 | 0.031 |
| 40 | 13.333 | 10.000 | -0.132 | -0.090 | 0.011 |
| 41 | 16.667 | 10.000 | -0.090 | -0.076 | 0.002 |
| 42 | 20.000 | 10.000 | -0.033 | -0.059 | 0.000 |
| 43 | 0.000 | 12.000 | 0.067 | 0.006 | 0.056 |
| 44 | 3.333 | 12.000 | 0.096 | -0.012 | 0.054 |
| 45 | 6.667 | 12.000 | 0.189 | 0.046 | 0.057 |
| 46 | 10.000 | 12.000 | 0.006 | 0.007 | 0.025 |
| 47 | 13.333 | 12.000 | -0.092 | -0.019 | 0.004 |
| 48 | 16.667 | 12.000 | -0.039 | -0.010 | 0.002 |
| 49 | 20.000 | 12.000 | 0.011 | 0.030 | 0.001 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-3 .SX PAGE 2

INTERVAL = 400 TIME = 0.040 DISTANCE = 4.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.129 | -0.052 | -0.066 |
| 2 | 3.333 | 0.000 | 0.234 | 0.038 | -0.072 |
| 3 | 6.667 | 0.000 | 0.160 | -0.002 | -0.052 |
| 4 | 10.000 | 0.000 | 0.148 | 0.019 | -0.035 |
| 5 | 13.333 | 0.000 | 0.072 | -0.027 | -0.010 |
| 6 | 16.667 | 0.000 | 0.100 | 0.014 | 0.003 |
| 7 | 20.000 | 0.000 | 0.014 | 0.036 | 0.010 |
| 8 | 0.000 | 2.000 | -0.013 | -0.272 | -0.028 |
| 9 | 3.333 | 2.000 | 0.137 | -0.108 | -0.048 |
| 10 | 6.667 | 2.000 | 0.182 | -0.035 | -0.048 |
| 11 | 10.000 | 2.000 | 0.099 | -0.067 | -0.034 |
| 12 | 13.333 | 2.000 | 0.082 | -0.061 | -0.018 |
| 13 | 16.667 | 2.000 | 0.010 | -0.127 | -0.002 |
| 14 | 20.000 | 2.000 | -0.025 | -0.163 | 0.007 |
| 15 | 0.000 | 4.000 | -0.013 | -0.190 | 0.007 |
| 16 | 3.333 | 4.000 | 0.115 | -0.126 | -0.014 |
| 17 | 6.667 | 4.000 | 0.185 | -0.034 | -0.028 |
| 18 | 10.000 | 4.000 | 0.133 | -0.010 | -0.024 |
| 19 | 13.333 | 4.000 | 0.108 | 0.022 | -0.018 |
| 20 | 16.667 | 4.000 | 0.083 | 0.031 | -0.012 |
| 21 | 20.000 | 4.000 | 0.048 | -0.031 | -0.008 |
| 22 | 0.000 | 6.000 | 0.016 | 0.000 | 0.000 |
| 23 | 3.333 | 6.000 | 0.138 | -0.032 | 0.000 |
| 24 | 6.667 | 6.000 | 0.162 | -0.053 | 0.000 |
| 25 | 10.000 | 6.000 | 0.176 | 0.030 | 0.000 |
| 26 | 13.333 | 6.000 | 0.118 | 0.059 | 0.000 |
| 27 | 16.667 | 6.000 | 0.161 | 0.162 | 0.000 |
| 28 | 20.000 | 6.000 | 0.109 | 0.145 | 0.000 |
| 29 | 0.000 | 8.000 | -0.013 | -0.190 | -0.007 |
| 30 | 3.333 | 8.000 | 0.115 | -0.126 | 0.014 |
| 31 | 6.667 | 8.000 | 0.185 | -0.034 | 0.028 |
| 32 | 10.000 | 8.000 | 0.133 | -0.010 | 0.024 |
| 33 | 13.333 | 8.000 | 0.108 | 0.022 | 0.018 |
| 34 | 16.667 | 8.000 | 0.083 | 0.031 | 0.012 |
| 35 | 20.000 | 8.000 | 0.048 | -0.031 | 0.008 |
| 36 | 0.000 | 10.000 | -0.013 | -0.272 | 0.028 |
| 37 | 3.333 | 10.000 | 0.137 | -0.108 | 0.048 |
| 38 | 6.667 | 10.000 | 0.182 | -0.035 | 0.048 |
| 39 | 10.000 | 10.000 | 0.099 | -0.067 | 0.034 |
| 40 | 13.333 | 10.000 | 0.082 | -0.061 | 0.018 |
| 41 | 16.667 | 10.000 | 0.010 | -0.127 | 0.002 |
| 42 | 20.000 | 10.000 | -0.025 | -0.163 | -0.007 |
| 43 | 0.000 | 12.000 | 0.129 | -0.052 | 0.066 |
| 44 | 3.333 | 12.000 | 0.234 | 0.038 | 0.072 |
| 45 | 6.667 | 12.000 | 0.160 | -0.002 | 0.052 |
| 46 | 10.000 | 12.000 | 0.148 | 0.019 | 0.035 |
| 47 | 13.333 | 12.000 | 0.072 | -0.027 | 0.010 |
| 48 | 16.667 | 12.000 | 0.100 | 0.014 | -0.003 |
| 49 | 20.000 | 12.000 | 0.014 | 0.036 | -0.010 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-4 .SX PAGE 1

INTERVAL = 200 TIME = 0.040 DISTANCE = 2.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.056 | 0.052 | -0.032 |
| 2 | 3.333 | 0.000 | -0.165 | 0.020 | -0.032 |
| 3 | 6.667 | 0.000 | -0.073 | -0.048 | -0.018 |
| 4 | 10.000 | 0.000 | 0.157 | -0.028 | 0.021 |
| 5 | 13.333 | 0.000 | 0.200 | 0.042 | 0.028 |
| 6 | 16.667 | 0.000 | 0.034 | 0.004 | 0.035 |
| 7 | 20.000 | 0.000 | 0.009 | 0.008 | 0.040 |
| 8 | 0.000 | 2.000 | -0.103 | -0.131 | -0.006 |
| 9 | 3.333 | 2.000 | -0.312 | -0.193 | -0.007 |
| 10 | 6.667 | 2.000 | -0.030 | 0.026 | -0.012 |
| 11 | 10.000 | 2.000 | 0.219 | 0.089 | 0.005 |
| 12 | 13.333 | 2.000 | 0.153 | -0.033 | 0.021 |
| 13 | 16.667 | 2.000 | 0.032 | -0.074 | 0.038 |
| 14 | 20.000 | 2.000 | 0.005 | -0.026 | 0.047 |
| 15 | 0.000 | 4.000 | -0.116 | -0.051 | 0.015 |
| 16 | 3.333 | 4.000 | -0.282 | -0.166 | 0.023 |
| 17 | 6.667 | 4.000 | -0.077 | -0.046 | 0.010 |
| 18 | 10.000 | 4.000 | 0.204 | 0.065 | -0.008 |
| 19 | 13.333 | 4.000 | 0.212 | 0.028 | 0.003 |
| 20 | 16.667 | 4.000 | 0.055 | -0.070 | 0.031 |
| 21 | 20.000 | 4.000 | -0.035 | -0.127 | 0.043 |
| 22 | 0.000 | 6.000 | 0.046 | 0.271 | 0.000 |
| 23 | 3.333 | 6.000 | -0.151 | 0.054 | 0.000 |
| 24 | 6.667 | 6.000 | -0.162 | -0.049 | 0.000 |
| 25 | 10.000 | 6.000 | 0.117 | -0.013 | 0.000 |
| 26 | 13.333 | 6.000 | 0.270 | 0.064 | 0.000 |
| 27 | 16.667 | 6.000 | 0.095 | -0.031 | 0.000 |
| 28 | 20.000 | 6.000 | -0.005 | -0.099 | 0.000 |
| 29 | 0.000 | 8.000 | -0.116 | -0.051 | -0.015 |
| 30 | 3.333 | 8.000 | -0.282 | -0.166 | -0.023 |
| 31 | 6.667 | 8.000 | -0.077 | -0.046 | -0.010 |
| 32 | 10.000 | 8.000 | 0.204 | 0.065 | 0.009 |
| 33 | 13.333 | 8.000 | 0.212 | 0.028 | -0.003 |
| 34 | 16.667 | 8.000 | 0.055 | -0.070 | -0.030 |
| 35 | 20.000 | 8.000 | -0.035 | -0.127 | -0.043 |
| 36 | 0.000 | 10.000 | -0.103 | -0.131 | 0.006 |
| 37 | 3.333 | 10.000 | -0.312 | -0.193 | 0.007 |
| 38 | 6.667 | 10.000 | -0.030 | 0.026 | 0.012 |
| 39 | 10.000 | 10.000 | 0.219 | 0.089 | -0.005 |
| 40 | 13.333 | 10.000 | 0.153 | -0.033 | -0.021 |
| 41 | 16.667 | 10.000 | 0.032 | -0.074 | -0.038 |
| 42 | 20.000 | 10.000 | 0.005 | -0.026 | -0.047 |
| 43 | 0.000 | 12.000 | -0.057 | 0.052 | 0.032 |
| 44 | 3.333 | 12.000 | -0.165 | 0.020 | 0.032 |
| 45 | 6.667 | 12.000 | -0.073 | -0.048 | 0.018 |
| 46 | 10.000 | 12.000 | 0.157 | -0.028 | -0.021 |
| 47 | 13.333 | 12.000 | 0.200 | 0.042 | -0.028 |
| 48 | 16.667 | 12.000 | 0.034 | 0.004 | -0.035 |
| 49 | 20.000 | 12.000 | 0.009 | 0.008 | -0.040 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-4 .SX PAGE 2

INTERVAL = 400 TIME = 0.080 DISTANCE = 4.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.037 | 0.012 | 0.007 |
| 2 | 3.333 | 0.000 | -0.139 | 0.020 | 0.007 |
| 3 | 6.667 | 0.000 | -0.084 | -0.056 | 0.001 |
| 4 | 10.000 | 0.000 | 0.216 | -0.016 | 0.004 |
| 5 | 13.333 | 0.000 | 0.304 | 0.040 | 0.014 |
| 6 | 16.667 | 0.000 | 0.155 | 0.025 | 0.021 |
| 7 | 20.000 | 0.000 | -0.003 | -0.013 | 0.028 |
| 8 | 0.000 | 2.000 | -0.084 | -0.171 | 0.019 |
| 9 | 3.333 | 2.000 | -0.318 | -0.270 | 0.023 |
| 10 | 6.667 | 2.000 | -0.144 | -0.119 | 0.011 |
| 11 | 10.000 | 2.000 | 0.188 | -0.001 | 0.002 |
| 12 | 13.333 | 2.000 | 0.309 | 0.016 | 0.015 |
| 13 | 16.667 | 2.000 | 0.174 | -0.009 | 0.024 |
| 14 | 20.000 | 2.000 | 0.028 | -0.055 | 0.025 |
| 15 | 0.000 | 4.000 | -0.101 | -0.018 | 0.018 |
| 16 | 3.333 | 4.000 | -0.267 | -0.181 | 0.031 |
| 17 | 6.667 | 4.000 | -0.187 | -0.153 | 0.031 |
| 18 | 10.000 | 4.000 | 0.180 | -0.012 | 0.005 |
| 19 | 13.333 | 4.000 | 0.339 | 0.014 | 0.009 |
| 20 | 16.667 | 4.000 | 0.131 | -0.098 | 0.023 |
| 21 | 20.000 | 4.000 | 0.020 | -0.104 | 0.020 |
| 22 | 0.000 | 6.000 | 0.034 | 0.362 | 0.000 |
| 23 | 3.333 | 6.000 | -0.007 | 0.253 | 0.000 |
| 24 | 6.667 | 6.000 | -0.171 | 0.039 | 0.000 |
| 25 | 10.000 | 6.000 | 0.127 | 0.036 | 0.000 |
| 26 | 13.333 | 6.000 | 0.367 | 0.045 | 0.000 |
| 27 | 16.667 | 6.000 | 0.164 | -0.099 | 0.000 |
| 28 | 20.000 | 6.000 | 0.014 | -0.167 | 0.000 |
| 29 | 0.000 | 8.000 | -0.101 | -0.018 | -0.018 |
| 30 | 3.333 | 8.000 | -0.267 | -0.184 | -0.031 |
| 31 | 6.667 | 8.000 | -0.187 | -0.153 | -0.031 |
| 32 | 10.000 | 8.000 | 0.180 | -0.012 | -0.005 |
| 33 | 13.333 | 8.000 | 0.339 | 0.014 | -0.009 |
| 34 | 16.667 | 8.000 | 0.131 | -0.098 | -0.023 |
| 35 | 20.000 | 8.000 | 0.020 | -0.104 | -0.020 |
| 36 | 0.000 | 10.000 | -0.084 | -0.171 | -0.019 |
| 37 | 3.333 | 10.000 | -0.318 | -0.270 | -0.023 |
| 38 | 6.667 | 10.000 | -0.144 | -0.119 | -0.011 |
| 39 | 10.000 | 10.000 | 0.188 | -0.001 | -0.002 |
| 40 | 13.333 | 10.000 | 0.309 | 0.016 | -0.015 |
| 41 | 16.667 | 10.000 | 0.174 | -0.009 | -0.024 |
| 42 | 20.000 | 10.000 | 0.028 | -0.055 | -0.025 |
| 43 | 0.000 | 12.000 | -0.037 | 0.012 | -0.007 |
| 44 | 3.333 | 12.000 | -0.139 | 0.020 | -0.007 |
| 45 | 6.667 | 12.000 | -0.084 | -0.056 | -0.001 |
| 46 | 10.000 | 12.000 | 0.216 | -0.016 | -0.004 |
| 47 | 13.333 | 12.000 | 0.304 | 0.040 | -0.014 |
| 48 | 16.667 | 12.000 | 0.155 | 0.025 | -0.021 |
| 49 | 20.000 | 12.000 | -0.003 | -0.013 | -0.028 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-5 .SX PAGE 1

INTERVAL = 200 TIME = 0.040 DISTANCE = 2.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.290 | -0.147 | -0.046 |
| 2 | 3.333 | 0.000 | 0.621 | 0.083 | -0.070 |
| 3 | 6.667 | 0.000 | 0.450 | 0.022 | -0.047 |
| 4 | 10.000 | 0.000 | 0.261 | 0.022 | -0.038 |
| 5 | 13.333 | 0.000 | 0.068 | -0.002 | -0.030 |
| 6 | 16.667 | 0.000 | 0.016 | -0.004 | -0.002 |
| 7 | 20.000 | 0.000 | 0.027 | 0.053 | 0.015 |
| 8 | 0.000 | 2.000 | 0.075 | -0.410 | 0.010 |
| 9 | 3.333 | 2.000 | 0.501 | -0.067 | -0.028 |
| 10 | 6.667 | 2.000 | 0.549 | 0.061 | -0.037 |
| 11 | 10.000 | 2.000 | 0.252 | -0.042 | -0.041 |
| 12 | 13.333 | 2.000 | 0.020 | -0.142 | -0.036 |
| 13 | 16.667 | 2.000 | -0.055 | -0.169 | -0.002 |
| 14 | 20.000 | 2.000 | -0.045 | -0.152 | 0.018 |
| 15 | 0.000 | 4.000 | -0.033 | -0.419 | 0.088 |
| 16 | 3.333 | 4.000 | 0.451 | -0.138 | 0.030 |
| 17 | 6.667 | 4.000 | 0.480 | -0.047 | -0.006 |
| 18 | 10.000 | 4.000 | 0.243 | -0.022 | -0.031 |
| 19 | 13.333 | 4.000 | 0.101 | 0.014 | -0.034 |
| 20 | 16.667 | 4.000 | 0.045 | 0.022 | -0.005 |
| 21 | 20.000 | 4.000 | 0.022 | -0.047 | 0.009 |
| 22 | 0.000 | 6.000 | 0.083 | 0.269 | 0.045 |
| 23 | 3.333 | 6.000 | 0.491 | 0.096 | 0.035 |
| 24 | 6.667 | 6.000 | 0.444 | -0.113 | 0.020 |
| 25 | 10.000 | 6.000 | 0.252 | -0.078 | 0.011 |
| 26 | 13.333 | 6.000 | 0.152 | 0.072 | 0.004 |
| 27 | 16.667 | 6.000 | 0.138 | 0.185 | 0.009 |
| 28 | 20.000 | 6.000 | 0.099 | 0.186 | 0.012 |
| 29 | 0.000 | 8.000 | -0.030 | -0.423 | 0.001 |
| 30 | 3.333 | 8.000 | 0.402 | -0.162 | 0.044 |
| 31 | 6.667 | 8.000 | 0.504 | 0.009 | 0.053 |
| 32 | 10.000 | 8.000 | 0.239 | 0.020 | 0.046 |
| 33 | 13.333 | 8.000 | 0.098 | 0.031 | 0.039 |
| 34 | 16.667 | 8.000 | 0.064 | 0.059 | 0.032 |
| 35 | 20.000 | 8.000 | 0.054 | 0.037 | 0.033 |
| 36 | 0.000 | 10.000 | 0.075 | -0.395 | 0.076 |
| 37 | 3.333 | 10.000 | 0.450 | -0.081 | 0.114 |
| 38 | 6.667 | 10.000 | 0.527 | 0.091 | 0.098 |
| 39 | 10.000 | 10.000 | 0.209 | -0.021 | 0.049 |
| 40 | 13.333 | 10.000 | 0.041 | -0.105 | 0.040 |
| 41 | 16.667 | 10.000 | -0.007 | -0.116 | 0.040 |
| 42 | 20.000 | 10.000 | -0.010 | -0.111 | 0.037 |
| 43 | 0.000 | 12.000 | 0.263 | -0.153 | 0.127 |
| 44 | 3.333 | 12.000 | 0.612 | 0.115 | 0.163 |
| 45 | 6.667 | 12.000 | 0.365 | 0.030 | 0.107 |
| 46 | 10.000 | 12.000 | 0.172 | -0.014 | 0.040 |
| 47 | 13.333 | 12.000 | 0.111 | -0.001 | 0.037 |
| 48 | 16.667 | 12.000 | 0.069 | 0.015 | 0.045 |
| 49 | 20.000 | 12.000 | 0.015 | 0.025 | 0.042 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-5 .SX PAGE 2

INTERVAL = 400 TIME = 0.080 DISTANCE = 4.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.167 | 0.080 | 0.119 |
| 2 | 3.333 | 0.000 | -0.301 | -0.183 | 0.112 |
| 3 | 6.667 | 0.000 | 0.243 | 0.003 | -0.005 |
| 4 | 10.000 | 0.000 | 0.328 | 0.071 | -0.087 |
| 5 | 13.333 | 0.000 | 0.141 | 0.019 | -0.088 |
| 6 | 16.667 | 0.000 | 0.018 | -0.034 | -0.067 |
| 7 | 20.000 | 0.000 | -0.005 | 0.020 | -0.060 |
| 8 | 0.000 | 2.000 | -0.059 | 0.167 | 0.088 |
| 9 | 3.333 | 2.000 | -0.288 | -0.056 | 0.083 |
| 10 | 6.667 | 2.000 | 0.039 | -0.067 | -0.005 |
| 11 | 10.000 | 2.000 | 0.272 | 0.016 | -0.064 |
| 12 | 13.333 | 2.000 | 0.241 | 0.100 | -0.079 |
| 13 | 16.667 | 2.000 | 0.068 | 0.036 | -0.083 |
| 14 | 20.000 | 2.000 | -0.044 | -0.100 | -0.083 |
| 15 | 0.000 | 4.000 | -0.106 | 0.040 | 0.068 |
| 16 | 3.333 | 4.000 | -0.389 | -0.135 | 0.057 |
| 17 | 6.667 | 4.000 | 0.052 | 0.033 | -0.020 |
| 18 | 10.000 | 4.000 | 0.280 | 0.059 | -0.039 |
| 19 | 13.333 | 4.000 | 0.195 | 0.070 | -0.062 |
| 20 | 16.667 | 4.000 | 0.038 | 0.054 | -0.101 |
| 21 | 20.000 | 4.000 | 0.036 | 0.047 | -0.125 |
| 22 | 0.000 | 6.000 | 0.002 | 0.016 | 0.082 |
| 23 | 3.333 | 6.000 | -0.408 | -0.098 | 0.050 |
| 24 | 6.667 | 6.000 | 0.045 | 0.188 | -0.008 |
| 25 | 10.000 | 6.000 | 0.310 | 0.138 | -0.037 |
| 26 | 13.333 | 6.000 | 0.132 | -0.032 | -0.059 |
| 27 | 16.667 | 6.000 | -0.002 | -0.021 | -0.085 |
| 28 | 20.000 | 6.000 | 0.038 | 0.109 | -0.101 |
| 29 | 0.000 | 8.000 | -0.066 | 0.096 | 0.084 |
| 30 | 3.333 | 8.000 | -0.510 | -0.193 | 0.025 |
| 31 | 6.667 | 8.000 | -0.008 | -0.017 | -0.005 |
| 32 | 10.000 | 8.000 | 0.237 | -0.012 | -0.042 |
| 33 | 13.333 | 8.000 | 0.108 | -0.036 | -0.052 |
| 34 | 16.667 | 8.000 | 0.012 | 0.053 | -0.045 |
| 35 | 20.000 | 8.000 | 0.052 | 0.163 | -0.038 |
| 36 | 0.000 | 10.000 | -0.052 | 0.254 | 0.027 |
| 37 | 3.333 | 10.000 | -0.495 | -0.146 | -0.025 |
| 38 | 6.667 | 10.000 | -0.093 | -0.140 | -0.024 |
| 39 | 10.000 | 10.000 | 0.205 | -0.045 | -0.020 |
| 40 | 13.333 | 10.000 | 0.174 | 0.057 | -0.012 |
| 41 | 16.667 | 10.000 | 0.030 | 0.075 | -0.016 |
| 42 | 20.000 | 10.000 | 0.001 | 0.042 | -0.019 |
| 43 | 0.000 | 12.000 | -0.249 | 0.123 | -0.038 |
| 44 | 3.333 | 12.000 | -0.505 | -0.199 | -0.077 |
| 45 | 6.667 | 12.000 | 0.093 | -0.023 | -0.034 |
| 46 | 10.000 | 12.000 | 0.289 | 0.071 | 0.003 |
| 47 | 13.333 | 12.000 | 0.132 | 0.054 | 0.010 |
| 48 | 16.667 | 12.000 | -0.054 | -0.022 | -0.014 |
| 49 | 20.000 | 12.000 | 0.000 | -0.009 | -0.021 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-6 .SX PAGE 1

INTERVAL = 200 TIME = 0.040 DISTANCE = 2.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.336 | -0.148 | -0.028 |
| 2 | 3.333 | 0.000 | 0.668 | 0.067 | -0.041 |
| 3 | 6.667 | 0.000 | 0.543 | 0.025 | -0.036 |
| 4 | 10.000 | 0.000 | 0.314 | 0.047 | -0.067 |
| 5 | 13.333 | 0.000 | 0.009 | -0.009 | -0.066 |
| 6 | 16.667 | 0.000 | -0.030 | -0.021 | -0.021 |
| 7 | 20.000 | 0.000 | 0.037 | 0.078 | 0.004 |
| 8 | 0.000 | 2.000 | 0.078 | -0.473 | 0.040 |
| 9 | 3.333 | 2.000 | 0.558 | -0.082 | 0.004 |
| 10 | 6.667 | 2.000 | 0.611 | 0.055 | -0.020 |
| 11 | 10.000 | 2.000 | 0.279 | -0.049 | -0.065 |
| 12 | 13.333 | 2.000 | -0.038 | -0.180 | -0.075 |
| 13 | 16.667 | 2.000 | -0.104 | -0.207 | -0.026 |
| 14 | 20.000 | 2.000 | -0.077 | -0.196 | 0.006 |
| 15 | 0.000 | 4.000 | -0.047 | -0.471 | 0.136 |
| 16 | 3.333 | 4.000 | 0.515 | -0.140 | 0.066 |
| 17 | 6.667 | 4.000 | 0.505 | -0.077 | 0.010 |
| 18 | 10.000 | 4.000 | 0.234 | -0.046 | -0.050 |
| 19 | 13.333 | 4.000 | 0.056 | 0.006 | -0.071 |
| 20 | 16.667 | 4.000 | 0.021 | 0.029 | -0.033 |
| 21 | 20.000 | 4.000 | 0.016 | -0.060 | -0.013 |
| 22 | 0.000 | 6.000 | 0.089 | 0.295 | 0.092 |
| 23 | 3.333 | 6.000 | 0.536 | 0.106 | 0.072 |
| 24 | 6.667 | 6.000 | 0.473 | -0.123 | 0.035 |
| 25 | 10.000 | 6.000 | 0.229 | -0.095 | 0.002 |
| 26 | 13.333 | 6.000 | 0.104 | 0.073 | -0.022 |
| 27 | 16.667 | 6.000 | 0.128 | 0.233 | -0.012 |
| 28 | 20.000 | 6.000 | 0.114 | 0.259 | -0.007 |
| 29 | 0.000 | 8.000 | -0.025 | -0.446 | 0.043 |
| 30 | 3.333 | 8.000 | 0.420 | -0.176 | 0.082 |
| 31 | 6.667 | 8.000 | 0.535 | 0.034 | 0.074 |
| 32 | 10.000 | 8.000 | 0.200 | 0.032 | 0.040 |
| 33 | 13.333 | 8.000 | 0.052 | 0.051 | 0.023 |
| 34 | 16.667 | 8.000 | 0.061 | 0.121 | 0.029 |
| 35 | 20.000 | 8.000 | 0.082 | 0.137 | 0.038 |
| 36 | 0.000 | 10.000 | 0.077 | -0.425 | 0.122 |
| 37 | 3.333 | 10.000 | 0.468 | -0.088 | 0.162 |
| 38 | 6.667 | 10.000 | 0.533 | 0.108 | 0.127 |
| 39 | 10.000 | 10.000 | 0.145 | -0.022 | 0.045 |
| 40 | 13.333 | 10.000 | 0.006 | -0.087 | 0.031 |
| 41 | 16.667 | 10.000 | -0.008 | -0.081 | 0.048 |
| 42 | 20.000 | 10.000 | 0.008 | -0.075 | 0.056 |
| 43 | 0.000 | 12.000 | 0.276 | -0.166 | 0.176 |
| 44 | 3.333 | 12.000 | 0.653 | 0.143 | 0.217 |
| 45 | 6.667 | 12.000 | 0.325 | 0.045 | 0.137 |
| 46 | 10.000 | 12.000 | 0.084 | -0.031 | 0.033 |
| 47 | 13.333 | 12.000 | 0.090 | -0.004 | 0.031 |
| 48 | 16.667 | 12.000 | 0.074 | 0.023 | 0.057 |
| 49 | 20.000 | 12.000 | 0.009 | 0.008 | 0.062 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-6 .SX PAGE 2

INTERVAL = 400 TIME = 0.080 DISTANCE = 4.000

| JOINT | X (FT) | Y (FT) | Mx (K.FT/FT) | My (K.FT/FT) | Mxy (K.FT/FT) |
|---|---|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.123 | 0.074 | 0.155 |
| 2 | 3.333 | 0.000 | -0.234 | -0.182 | 0.141 |
| 3 | 6.667 | 0.000 | 0.293 | 0.005 | 0.001 |
| 4 | 10.000 | 0.000 | 0.380 | 0.062 | -0.110 |
| 5 | 13.333 | 0.000 | 0.230 | 0.022 | -0.121 |
| 6 | 16.667 | 0.000 | 0.067 | -0.040 | -0.099 |
| 7 | 20.000 | 0.000 | -0.007 | 0.031 | -0.087 |
| 8 | 0.000 | 2.000 | -0.057 | 0.121 | 0.142 |
| 9 | 3.333 | 2.000 | -0.190 | -0.007 | 0.118 |
| 10 | 6.667 | 2.000 | 0.066 | -0.060 | 0.003 |
| 11 | 10.000 | 2.000 | 0.309 | 0.026 | -0.083 |
| 12 | 13.333 | 2.000 | 0.363 | 0.152 | -0.114 |
| 13 | 16.667 | 2.000 | 0.123 | 0.029 | -0.124 |
| 14 | 20.000 | 2.000 | -0.061 | -0.168 | -0.122 |
| 15 | 0.000 | 4.000 | -0.133 | -0.042 | 0.150 |
| 16 | 3.333 | 4.000 | -0.336 | -0.134 | 0.107 |
| 17 | 6.667 | 4.000 | 0.059 | 0.030 | -0.011 |
| 18 | 10.000 | 4.000 | 0.309 | 0.076 | -0.052 |
| 19 | 13.333 | 4.000 | 0.305 | 0.132 | -0.101 |
| 20 | 16.667 | 4.000 | 0.087 | 0.058 | -0.166 |
| 21 | 20.000 | 4.000 | 0.030 | -0.017 | -0.195 |
| 22 | 0.000 | 6.000 | -0.001 | -0.051 | 0.176 |
| 23 | 3.333 | 6.000 | -0.434 | -0.168 | 0.116 |
| 24 | 6.667 | 6.000 | 0.028 | 0.149 | 0.007 |
| 25 | 10.000 | 6.000 | 0.318 | 0.120 | -0.043 |
| 26 | 13.333 | 6.000 | 0.172 | -0.045 | -0.093 |
| 27 | 16.667 | 6.000 | 0.032 | -0.034 | -0.161 |
| 28 | 20.000 | 6.000 | 0.044 | 0.092 | -0.194 |
| 29 | 0.000 | 8.000 | -0.040 | 0.101 | 0.175 |
| 30 | 3.333 | 8.000 | -0.564 | -0.228 | 0.083 |
| 31 | 6.667 | 8.000 | -0.052 | -0.070 | 0.008 |
| 32 | 10.000 | 8.000 | 0.226 | -0.076 | -0.048 |
| 33 | 13.333 | 8.000 | 0.097 | -0.097 | -0.078 |
| 34 | 16.667 | 8.000 | 0.034 | 0.063 | -0.105 |
| 35 | 20.000 | 8.000 | 0.064 | 0.225 | -0.112 |
| 36 | 0.000 | 10.000 | -0.033 | 0.327 | 0.097 |
| 37 | 3.333 | 10.000 | -0.575 | -0.166 | 0.014 |
| 38 | 6.667 | 10.000 | -0.166 | -0.195 | -0.019 |
| 39 | 10.000 | 10.000 | 0.200 | -0.081 | -0.023 |
| 40 | 13.333 | 10.000 | 0.163 | 0.037 | -0.021 |
| 41 | 16.667 | 10.000 | 0.037 | 0.111 | -0.048 |
| 42 | 20.000 | 10.000 | 0.028 | 0.124 | -0.060 |
| 43 | 0.000 | 12.000 | -0.294 | 0.145 | 0.009 |
| 44 | 3.333 | 12.000 | -0.614 | -0.220 | -0.054 |
| 45 | 6.667 | 12.000 | 0.037 | -0.047 | -0.036 |
| 46 | 10.000 | 12.000 | 0.322 | 0.089 | 0.003 |
| 47 | 13.333 | 12.000 | 0.132 | 0.073 | 0.009 |
| 48 | 16.667 | 12.000 | -0.086 | -0.013 | -0.036 |
| 49 | 20.000 | 12.000 | 0.004 | -0.029 | -0.050 |

UNIVERSITY OF PUERTO RICO     FILE NAME = EXAM1-1 .SOI     PAGE 1

INTERVAL = 200     TIME = 0.040     DISTANCE 2.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.43431 |
| 2 | 3.333 | 0.000 | -0.59936 |
| 3 | 6.667 | 0.000 | -0.41796 |
| 4 | 10.000 | 0.000 | -0.39837 |
| 5 | 13.333 | 0.000 | -0.44160 |
| 6 | 16.667 | 0.000 | -0.52687 |
| 7 | 20.000 | 0.000 | -0.29580 |
| 8 | 0.000 | 2.000 | -1.12887 |
| 9 | 3.333 | 2.000 | -1.36013 |
| 10 | 6.667 | 2.000 | -0.84142 |
| 11 | 10.000 | 2.000 | -0.74440 |
| 12 | 13.333 | 2.000 | -0.86806 |
| 13 | 16.667 | 2.000 | -1.08439 |
| 14 | 20.000 | 2.000 | -0.64454 |
| 15 | 0.000 | 4.000 | -1.17185 |
| 16 | 3.333 | 4.000 | -1.44136 |
| 17 | 6.667 | 4.000 | -0.89440 |
| 18 | 10.000 | 4.000 | -0.76835 |
| 19 | 13.333 | 4.000 | -0.86607 |
| 20 | 16.667 | 4.000 | -1.06654 |
| 21 | 20.000 | 4.000 | -0.63581 |
| 22 | 0.000 | 6.000 | -1.16904 |
| 23 | 3.333 | 6.000 | -1.45658 |
| 24 | 6.667 | 6.000 | -0.91559 |
| 25 | 10.000 | 6.000 | -0.77741 |
| 26 | 13.333 | 6.000 | -0.85899 |
| 27 | 16.667 | 6.000 | -1.04886 |
| 28 | 20.000 | 6.000 | -0.62627 |
| 29 | 0.000 | 8.000 | -1.17186 |
| 30 | 3.333 | 8.000 | -1.44137 |
| 31 | 6.667 | 8.000 | -0.89441 |
| 32 | 10.000 | 8.000 | -0.76836 |
| 33 | 13.333 | 8.000 | -0.86607 |
| 34 | 16.667 | 8.000 | -1.06654 |
| 35 | 20.000 | 8.000 | -0.63581 |
| 36 | 0.000 | 10.000 | -1.12887 |
| 37 | 3.333 | 10.000 | -1.36014 |
| 38 | 6.667 | 10.000 | -0.84143 |
| 39 | 10.000 | 10.000 | -0.74440 |
| 40 | 13.333 | 10.000 | -0.86807 |
| 41 | 16.667 | 10.000 | -1.08439 |
| 42 | 20.000 | 10.000 | -0.64454 |
| 43 | 0.000 | 12.000 | -0.43431 |
| 44 | 3.333 | 12.000 | -0.59936 |
| 45 | 6.667 | 12.000 | -0.41796 |
| 46 | 10.000 | 12.000 | -0.39838 |
| 47 | 13.333 | 12.000 | -0.44160 |
| 48 | 16.667 | 12.000 | -0.52687 |
| 49 | 20.000 | 12.000 | -0.29580 |
| | | | TOTAL = -40.1138 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-1 .SOI PAGE 2

INTERVAL = 400 TIME = 0.080 DISTANCE 4.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.45855 |
| 2 | 3.333 | 0.000 | -0.96643 |
| 3 | 6.667 | 0.000 | -0.74067 |
| 4 | 10.000 | 0.000 | -0.56046 |
| 5 | 13.333 | 0.000 | -0.52772 |
| 6 | 16.667 | 0.000 | -0.56343 |
| 7 | 20.000 | 0.000 | -0.28419 |
| 8 | 0.000 | 2.000 | -1.01872 |
| 9 | 3.333 | 2.000 | -1.93333 |
| 10 | 6.667 | 2.000 | -1.53211 |
| 11 | 10.000 | 2.000 | -1.16946 |
| 12 | 13.333 | 2.000 | -1.06477 |
| 13 | 16.667 | 2.000 | -1.12819 |
| 14 | 20.000 | 2.000 | -0.59050 |
| 15 | 0.000 | 4.000 | -1.00770 |
| 16 | 3.333 | 4.000 | -1.92884 |
| 17 | 6.667 | 4.000 | -1.53298 |
| 18 | 10.000 | 4.000 | -1.17165 |
| 19 | 13.333 | 4.000 | -1.06703 |
| 20 | 16.667 | 4.000 | -1.11536 |
| 21 | 20.000 | 4.000 | -0.57455 |
| 22 | 0.000 | 6.000 | -1.00423 |
| 23 | 3.333 | 6.000 | -1.92020 |
| 24 | 6.667 | 6.000 | -1.52318 |
| 25 | 10.000 | 6.000 | -1.16420 |
| 26 | 13.333 | 6.000 | -1.06907 |
| 27 | 16.667 | 6.000 | -1.11402 |
| 28 | 20.000 | 6.000 | -0.56768 |
| 29 | 0.000 | 8.000 | -1.00770 |
| 30 | 3.333 | 8.000 | -1.92883 |
| 31 | 6.667 | 8.000 | -1.53298 |
| 32 | 10.000 | 8.000 | -1.17165 |
| 33 | 13.333 | 8.000 | -1.06704 |
| 34 | 16.667 | 8.000 | -1.11537 |
| 35 | 20.000 | 8.000 | -0.57455 |
| 36 | 0.000 | 10.000 | -1.01872 |
| 37 | 3.333 | 10.000 | -1.93333 |
| 38 | 6.667 | 10.000 | -1.53211 |
| 39 | 10.000 | 10.000 | -1.16946 |
| 40 | 13.333 | 10.000 | -1.06479 |
| 41 | 16.667 | 10.000 | -1.12821 |
| 42 | 20.000 | 10.000 | -0.59051 |
| 43 | 0.000 | 12.000 | -0.45855 |
| 44 | 3.333 | 12.000 | -0.96643 |
| 45 | 6.667 | 12.000 | -0.74067 |
| 46 | 10.000 | 12.000 | -0.56046 |
| 47 | 13.333 | 12.000 | -0.52773 |
| 48 | 16.667 | 12.000 | -0.56345 |
| 49 | 20.000 | 12.000 | -0.28420 |
| | | | TOTAL = -50.2359 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-2 .SOI PAGE 1

INTERVAL = 100 TIME = 0.020 DISTANCE 2.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.26722 |
| 2 | 3.333 | 0.000 | -0.48669 |
| 3 | 6.667 | 0.000 | -0.45877 |
| 4 | 10.000 | 0.000 | -0.48768 |
| 5 | 13.333 | 0.000 | -0.52557 |
| 6 | 16.667 | 0.000 | -0.52874 |
| 7 | 20.000 | 0.000 | -0.25194 |
| 8 | 0.000 | 2.000 | -0.58859 |
| 9 | 3.333 | 2.000 | -1.04187 |
| 10 | 6.667 | 2.000 | -0.92057 |
| 11 | 10.000 | 2.000 | -0.96542 |
| 12 | 13.333 | 2.000 | -1.05722 |
| 13 | 16.667 | 2.000 | -1.05917 |
| 14 | 20.000 | 2.000 | -0.50172 |
| 15 | 0.000 | 4.000 | -0.61455 |
| 16 | 3.333 | 4.000 | -1.08802 |
| 17 | 6.667 | 4.000 | -0.94715 |
| 18 | 10.000 | 4.000 | -0.96677 |
| 19 | 13.333 | 4.000 | -1.03912 |
| 20 | 16.667 | 4.000 | -1.03680 |
| 21 | 20.000 | 4.000 | -0.49217 |
| 22 | 0.000 | 6.000 | -0.61953 |
| 23 | 3.333 | 6.000 | -1.09557 |
| 24 | 6.667 | 6.000 | -0.95817 |
| 25 | 10.000 | 6.000 | -0.97011 |
| 26 | 13.333 | 6.000 | -1.02639 |
| 27 | 16.667 | 6.000 | -1.02237 |
| 28 | 20.000 | 6.000 | -0.48672 |
| 29 | 0.000 | 8.000 | -0.61455 |
| 30 | 3.333 | 8.000 | -1.08802 |
| 31 | 6.667 | 8.000 | -0.94715 |
| 32 | 10.000 | 8.000 | -0.96677 |
| 33 | 13.333 | 8.000 | -1.03912 |
| 34 | 16.667 | 8.000 | -1.03680 |
| 35 | 20.000 | 8.000 | -0.49217 |
| 36 | 0.000 | 10.000 | -0.58859 |
| 37 | 3.333 | 10.000 | -1.04187 |
| 38 | 6.667 | 10.000 | -0.92057 |
| 39 | 10.000 | 10.000 | -0.96542 |
| 40 | 13.333 | 10.000 | -1.05722 |
| 41 | 16.667 | 10.000 | -1.05917 |
| 42 | 20.000 | 10.000 | -0.50172 |
| 43 | 0.000 | 12.000 | -0.26722 |
| 44 | 3.333 | 12.000 | -0.48669 |
| 45 | 6.667 | 12.000 | -0.45877 |
| 46 | 10.000 | 12.000 | -0.48768 |
| 47 | 13.333 | 12.000 | -0.52557 |
| 48 | 16.667 | 12.000 | -0.52874 |
| 49 | 20.000 | 12.000 | -0.25194 |
| | | | TOTAL = -36.8304 |

| UNIVERSITY OF PUERTO RICO | FILE NAME = EXAM1-2 .SOI | PAGE 2 |
|---|---|---|

INTERVAL = 200 TIME = 0.040 DISTANCE 4.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.31269 |
| 2 | 3.333 | 0.000 | -0.53538 |
| 3 | 6.667 | 0.000 | -0.46385 |
| 4 | 10.000 | 0.000 | -0.44764 |
| 5 | 13.333 | 0.000 | -0.46990 |
| 6 | 16.667 | 0.000 | -0.52704 |
| 7 | 20.000 | 0.000 | -0.28761 |
| 8 | 0.000 | 2.000 | -0.76178 |
| 9 | 3.333 | 2.000 | -1.19964 |
| 10 | 6.667 | 2.000 | -0.95550 |
| 11 | 10.000 | 2.000 | -0.88248 |
| 12 | 13.333 | 2.000 | -0.93814 |
| 13 | 16.667 | 2.000 | -1.08098 |
| 14 | 20.000 | 2.000 | -0.61967 |
| 15 | 0.000 | 4.000 | -0.80793 |
| 16 | 3.333 | 4.000 | -1.26375 |
| 17 | 6.667 | 4.000 | -0.99550 |
| 18 | 10.000 | 4.000 | -0.89518 |
| 19 | 13.333 | 4.000 | -0.92779 |
| 20 | 16.667 | 4.000 | -1.05995 |
| 21 | 20.000 | 4.000 | -0.61111 |
| 22 | 0.000 | 6.000 | -0.81400 |
| 23 | 3.333 | 6.000 | -1.27199 |
| 24 | 6.667 | 6.000 | -1.00893 |
| 25 | 10.000 | 6.000 | -0.89986 |
| 26 | 13.333 | 6.000 | -0.91744 |
| 27 | 16.667 | 6.000 | -1.04081 |
| 28 | 20.000 | 6.000 | -0.60188 |
| 29 | 0.000 | 8.000 | -0.80793 |
| 30 | 3.333 | 8.000 | -1.26375 |
| 31 | 6.667 | 8.000 | -0.99551 |
| 32 | 10.000 | 8.000 | -0.89518 |
| 33 | 13.333 | 8.000 | -0.92779 |
| 34 | 16.667 | 8.000 | -1.05994 |
| 35 | 20.000 | 8.000 | -0.61111 |
| 36 | 0.000 | 10.000 | -0.76179 |
| 37 | 3.333 | 10.000 | -1.19964 |
| 38 | 6.667 | 10.000 | -0.95550 |
| 39 | 10.000 | 10.000 | -0.88248 |
| 40 | 13.333 | 10.000 | -0.93814 |
| 41 | 16.667 | 10.000 | -1.08098 |
| 42 | 20.000 | 10.000 | -0.61967 |
| 43 | 0.000 | 12.000 | -0.31270 |
| 44 | 3.333 | 12.000 | -0.53538 |
| 45 | 6.667 | 12.000 | -0.46386 |
| 46 | 10.000 | 12.000 | -0.44764 |
| 47 | 13.333 | 12.000 | -0.46990 |
| 48 | 16.667 | 12.000 | -0.52704 |
| 49 | 20.000 | 12.000 | -0.28761 |
| | | | TOTAL = -38.6419 |

INTERVAL = 200 TIME = 0.020 DISTANCE 2.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.26787 |
| 2 | 3.333 | 0.000 | -0.49224 |
| 3 | 6.667 | 0.000 | -0.45989 |
| 4 | 10.000 | 0.000 | -0.48475 |
| 5 | 13.333 | 0.000 | -0.52223 |
| 6 | 16.667 | 0.000 | -0.52703 |
| 7 | 20.000 | 0.000 | -0.25269 |
| 8 | 0.000 | 2.000 | -0.59841 |
| 9 | 3.333 | 2.000 | -1.05153 |
| 10 | 6.667 | 2.000 | -0.92420 |
| 11 | 10.000 | 2.000 | -0.96181 |
| 12 | 13.333 | 2.000 | -1.05061 |
| 13 | 16.667 | 2.000 | -1.05965 |
| 14 | 20.000 | 2.000 | -0.50474 |
| 15 | 0.000 | 4.000 | -0.62119 |
| 16 | 3.333 | 4.000 | -1.09780 |
| 17 | 6.667 | 4.000 | -0.95277 |
| 18 | 10.000 | 4.000 | -0.96339 |
| 19 | 13.333 | 4.000 | -1.03252 |
| 20 | 16.667 | 4.000 | -1.03639 |
| 21 | 20.000 | 4.000 | -0.49538 |
| 22 | 0.000 | 6.000 | -0.62413 |
| 23 | 3.333 | 6.000 | -1.11013 |
| 24 | 6.667 | 6.000 | -0.96575 |
| 25 | 10.000 | 6.000 | -0.96613 |
| 26 | 13.333 | 6.000 | -1.02177 |
| 27 | 16.667 | 6.000 | -1.02142 |
| 28 | 20.000 | 6.000 | -0.48915 |
| 29 | 0.000 | 8.000 | -0.62119 |
| 30 | 3.333 | 8.000 | -1.09780 |
| 31 | 6.667 | 8.000 | -0.95277 |
| 32 | 10.000 | 8.000 | -0.96339 |
| 33 | 13.333 | 8.000 | -1.03252 |
| 34 | 16.667 | 8.000 | -1.03639 |
| 35 | 20.000 | 8.000 | -0.49538 |
| 36 | 0.000 | 10.000 | -0.59841 |
| 37 | 3.333 | 10.000 | -1.05153 |
| 38 | 6.667 | 10.000 | -0.92421 |
| 39 | 10.000 | 10.000 | -0.96182 |
| 40 | 13.333 | 10.000 | -1.05061 |
| 41 | 16.667 | 10.000 | -1.05965 |
| 42 | 20.000 | 10.000 | -0.50474 |
| 43 | 0.000 | 12.000 | -0.26787 |
| 44 | 3.333 | 12.000 | -0.49224 |
| 45 | 6.667 | 12.000 | -0.45989 |
| 46 | 10.000 | 12.000 | -0.48475 |
| 47 | 13.333 | 12.000 | -0.52223 |
| 48 | 16.667 | 12.000 | -0.52703 |
| 49 | 20.000 | 12.000 | -0.25269 |
| | | | TOTAL = -36.9127 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-3 .SOI PAGE 2

INTERVAL = 400 TIME = 0.040 DISTANCE 4.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.31677 |
| 2 | 3.333 | 0.000 | -0.54099 |
| 3 | 6.667 | 0.000 | -0.46228 |
| 4 | 10.000 | 0.000 | -0.44609 |
| 5 | 13.333 | 0.000 | -0.47192 |
| 6 | 16.667 | 0.000 | -0.52680 |
| 7 | 20.000 | 0.000 | -0.28709 |
| 8 | 0.000 | 2.000 | -0.77778 |
| 9 | 3.333 | 2.000 | -1.20617 |
| 10 | 6.667 | 2.000 | -0.95936 |
| 11 | 10.000 | 2.000 | -0.88619 |
| 12 | 13.333 | 2.000 | -0.93698 |
| 13 | 16.667 | 2.000 | -1.08150 |
| 14 | 20.000 | 2.000 | -0.62072 |
| 15 | 0.000 | 4.000 | -0.82337 |
| 16 | 3.333 | 4.000 | -1.26967 |
| 17 | 6.667 | 4.000 | -0.99544 |
| 18 | 10.000 | 4.000 | -0.89598 |
| 19 | 13.333 | 4.000 | -0.92896 |
| 20 | 16.667 | 4.000 | -1.06105 |
| 21 | 20.000 | 4.000 | -0.61116 |
| 22 | 0.000 | 6.000 | -0.83232 |
| 23 | 3.333 | 6.000 | -1.28547 |
| 24 | 6.667 | 6.000 | -1.00727 |
| 25 | 10.000 | 6.000 | -0.89473 |
| 26 | 13.333 | 6.000 | -0.92114 |
| 27 | 16.667 | 6.000 | -1.04228 |
| 28 | 20.000 | 6.000 | -0.60084 |
| 29 | 0.000 | 8.000 | -0.82338 |
| 30 | 3.333 | 8.000 | -1.26968 |
| 31 | 6.667 | 8.000 | -0.99544 |
| 32 | 10.000 | 8.000 | -0.89598 |
| 33 | 13.333 | 8.000 | -0.92895 |
| 34 | 16.667 | 8.000 | -1.06105 |
| 35 | 20.000 | 8.000 | -0.61116 |
| 36 | 0.000 | 10.000 | -0.77779 |
| 37 | 3.333 | 10.000 | -1.20618 |
| 38 | 6.667 | 10.000 | -0.95937 |
| 39 | 10.000 | 10.000 | -0.88619 |
| 40 | 13.333 | 10.000 | -0.93698 |
| 41 | 16.667 | 10.000 | -1.08150 |
| 42 | 20.000 | 10.000 | -0.62071 |
| 43 | 0.000 | 12.000 | -0.31677 |
| 44 | 3.333 | 12.000 | -0.54099 |
| 45 | 6.667 | 12.000 | -0.46228 |
| 46 | 10.000 | 12.000 | -0.44609 |
| 47 | 13.333 | 12.000 | -0.47192 |
| 48 | 16.667 | 12.000 | -0.52680 |
| 49 | 20.000 | 12.000 | -0.28709 |

TOTAL = -38.7966

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-4 .SOI PAGE 1

INTERVAL = 200 TIME = 0.040 DISTANCE 2.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.31527 |
| 2 | 3.333 | 0.000 | -0.75875 |
| 3 | 6.667 | 0.000 | -0.61459 |
| 4 | 10.000 | 0.000 | -0.43135 |
| 5 | 13.333 | 0.000 | -0.37883 |
| 6 | 16.667 | 0.000 | -0.42944 |
| 7 | 20.000 | 0.000 | -0.25825 |
| 8 | 0.000 | 2.000 | -0.76560 |
| 9 | 3.333 | 2.000 | -1.62649 |
| 10 | 6.667 | 2.000 | -1.27675 |
| 11 | 10.000 | 2.000 | -0.80457 |
| 12 | 13.333 | 2.000 | -0.66905 |
| 13 | 16.667 | 2.000 | -0.88858 |
| 14 | 20.000 | 2.000 | -0.58549 |
| 15 | 0.000 | 4.000 | -0.77051 |
| 16 | 3.333 | 4.000 | -1.63979 |
| 17 | 6.667 | 4.000 | -1.30511 |
| 18 | 10.000 | 4.000 | -0.82392 |
| 19 | 13.333 | 4.000 | -0.68294 |
| 20 | 16.667 | 4.000 | -0.94315 |
| 21 | 20.000 | 4.000 | -0.63965 |
| 22 | 0.000 | 6.000 | -0.74638 |
| 23 | 3.333 | 6.000 | -1.61594 |
| 24 | 6.667 | 6.000 | -1.32223 |
| 25 | 10.000 | 6.000 | -0.84295 |
| 26 | 13.333 | 6.000 | -0.67971 |
| 27 | 16.667 | 6.000 | -0.95583 |
| 28 | 20.000 | 6.000 | -0.65941 |
| 29 | 0.000 | 8.000 | -0.77051 |
| 30 | 3.333 | 8.000 | -1.63979 |
| 31 | 6.667 | 8.000 | -1.30511 |
| 32 | 10.000 | 8.000 | -0.82392 |
| 33 | 13.333 | 8.000 | -0.68294 |
| 34 | 16.667 | 8.000 | -0.94315 |
| 35 | 20.000 | 8.000 | -0.63965 |
| 36 | 0.000 | 10.000 | -0.76560 |
| 37 | 3.333 | 10.000 | -1.62649 |
| 38 | 6.667 | 10.000 | -1.27675 |
| 39 | 10.000 | 10.000 | -0.80457 |
| 40 | 13.333 | 10.000 | -0.66905 |
| 41 | 16.667 | 10.000 | -0.88858 |
| 42 | 20.000 | 10.000 | -0.58548 |
| 43 | 0.000 | 12.000 | -0.31527 |
| 44 | 3.333 | 12.000 | -0.75875 |
| 45 | 6.667 | 12.000 | -0.61459 |
| 46 | 10.000 | 12.000 | -0.43135 |
| 47 | 13.333 | 12.000 | -0.37883 |
| 48 | 16.667 | 12.000 | -0.42944 |
| 49 | 20.000 | 12.000 | -0.25824 |

TOTAL = -40.0386

INTERVAL = 400 TIME = 0.080 DISTANCE 4.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.43703 |
| 2 | 3.333 | 0.000 | -0.97042 |
| 3 | 6.667 | 0.000 | -0.73483 |
| 4 | 10.000 | 0.000 | -0.42550 |
| 5 | 13.333 | 0.000 | -0.33507 |
| 6 | 16.667 | 0.000 | -0.38621 |
| 7 | 20.000 | 0.000 | -0.27346 |
| 8 | 0.000 | 2.000 | -1.06484 |
| 9 | 3.333 | 2.000 | -2.05139 |
| 10 | 6.667 | 2.000 | -1.57711 |
| 11 | 10.000 | 2.000 | -0.87966 |
| 12 | 13.333 | 2.000 | -0.56287 |
| 13 | 16.667 | 2.000 | -0.77985 |
| 14 | 20.000 | 2.000 | -0.64344 |
| 15 | 0.000 | 4.000 | -1.04208 |
| 16 | 3.333 | 4.000 | -2.04185 |
| 17 | 6.667 | 4.000 | -1.61897 |
| 18 | 10.000 | 4.000 | -0.93585 |
| 19 | 13.333 | 4.000 | -0.61415 |
| 20 | 16.667 | 4.000 | -0.88436 |
| 21 | 20.000 | 4.000 | -0.70726 |
| 22 | 0.000 | 6.000 | -1.00561 |
| 23 | 3.333 | 6.000 | -1.97777 |
| 24 | 6.667 | 6.000 | -1.61213 |
| 25 | 10.000 | 6.000 | -0.95329 |
| 26 | 13.333 | 6.000 | -0.62386 |
| 27 | 16.667 | 6.000 | -0.92020 |
| 28 | 20.000 | 6.000 | -0.73664 |
| 29 | 0.000 | 8.000 | -1.04207 |
| 30 | 3.333 | 8.000 | -2.04185 |
| 31 | 6.667 | 8.000 | -1.61897 |
| 32 | 10.000 | 8.000 | -0.93584 |
| 33 | 13.333 | 8.000 | -0.61415 |
| 34 | 16.667 | 8.000 | -0.88436 |
| 35 | 20.000 | 8.000 | -0.70726 |
| 36 | 0.000 | 10.000 | -1.06483 |
| 37 | 3.333 | 10.000 | -2.05139 |
| 38 | 6.667 | 10.000 | -1.57710 |
| 39 | 10.000 | 10.000 | -0.87966 |
| 40 | 13.333 | 10.000 | -0.56287 |
| 41 | 16.667 | 10.000 | -0.77985 |
| 42 | 20.000 | 10.000 | -0.64343 |
| 43 | 0.000 | 12.000 | -0.43703 |
| 44 | 3.333 | 12.000 | -0.97042 |
| 45 | 6.667 | 12.000 | -0.73483 |
| 46 | 10.000 | 12.000 | -0.42550 |
| 47 | 13.333 | 12.000 | -0.33507 |
| 48 | 16.667 | 12.000 | -0.38621 |
| 49 | 20.000 | 12.000 | -0.27346 |
| | | | TOTAL = -45.7619 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-5 .SOI PAGE 1

INTERVAL = 200 TIME = 0.040 DISTANCE 2.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.46261 |
| 2 | 3.333 | 0.000 | -0.59682 |
| 3 | 6.667 | 0.000 | -0.38783 |
| 4 | 10.000 | 0.000 | -0.37006 |
| 5 | 13.333 | 0.000 | -0.42503 |
| 6 | 16.667 | 0.000 | -0.51463 |
| 7 | 20.000 | 0.000 | -0.28791 |
| 8 | 0.000 | 2.000 | -1.19038 |
| 9 | 3.333 | 2.000 | -1.35626 |
| 10 | 6.667 | 2.000 | -0.77156 |
| 11 | 10.000 | 2.000 | -0.67707 |
| 12 | 13.333 | 2.000 | -0.83211 |
| 13 | 16.667 | 2.000 | -1.06802 |
| 14 | 20.000 | 2.000 | -0.63262 |
| 15 | 0.000 | 4.000 | -1.21732 |
| 16 | 3.333 | 4.000 | -1.43330 |
| 17 | 6.667 | 4.000 | -0.84188 |
| 18 | 10.000 | 4.000 | -0.71806 |
| 19 | 13.333 | 4.000 | -0.84046 |
| 20 | 16.667 | 4.000 | -1.05870 |
| 21 | 20.000 | 4.000 | -0.63348 |
| 22 | 0.000 | 6.000 | -1.19329 |
| 23 | 3.333 | 6.000 | -1.43717 |
| 24 | 6.667 | 6.000 | -0.86810 |
| 25 | 10.000 | 6.000 | -0.74029 |
| 26 | 13.333 | 6.000 | -0.84584 |
| 27 | 16.667 | 6.000 | -1.05318 |
| 28 | 20.000 | 6.000 | -0.63287 |
| 29 | 0.000 | 8.000 | -1.17399 |
| 30 | 3.333 | 8.000 | -1.40319 |
| 31 | 6.667 | 8.000 | -0.84436 |
| 32 | 10.000 | 8.000 | -0.74318 |
| 33 | 13.333 | 8.000 | -0.87246 |
| 34 | 16.667 | 8.000 | -1.09691 |
| 35 | 20.000 | 8.000 | -0.66071 |
| 36 | 0.000 | 10.000 | -1.10261 |
| 37 | 3.333 | 10.000 | -1.29297 |
| 38 | 6.667 | 10.000 | -0.79160 |
| 39 | 10.000 | 10.000 | -0.73811 |
| 40 | 13.333 | 10.000 | -0.90123 |
| 41 | 16.667 | 10.000 | -1.15406 |
| 42 | 20.000 | 10.000 | -0.69941 |
| 43 | 0.000 | 12.000 | -0.40889 |
| 44 | 3.333 | 12.000 | -0.55149 |
| 45 | 6.667 | 12.000 | -0.40385 |
| 46 | 10.000 | 12.000 | -0.40453 |
| 47 | 13.333 | 12.000 | -0.46353 |
| 48 | 16.667 | 12.000 | -0.57576 |
| 49 | 20.000 | 12.000 | -0.32417 |
| | | | TOTAL = -39.6938 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-5 .SOI PAGE 2

INTERVAL = 400 TIME = 0.080 DISTANCE 4.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.38285 |
| 2 | 3.333 | 0.000 | -0.79176 |
| 3 | 6.667 | 0.000 | -0.58279 |
| 4 | 10.000 | 0.000 | -0.47827 |
| 5 | 13.333 | 0.000 | -0.49586 |
| 6 | 16.667 | 0.000 | -0.58714 |
| 7 | 20.000 | 0.000 | -0.31811 |
| 8 | 0.000 | 2.000 | -0.87768 |
| 9 | 3.333 | 2.000 | -1.64715 |
| 10 | 6.667 | 2.000 | -1.30108 |
| 11 | 10.000 | 2.000 | -1.02023 |
| 12 | 13.333 | 2.000 | -0.99818 |
| 13 | 16.667 | 2.000 | -1.16253 |
| 14 | 20.000 | 2.000 | -0.66774 |
| 15 | 0.000 | 4.000 | -0.88714 |
| 16 | 3.333 | 4.000 | -1.71941 |
| 17 | 6.667 | 4.000 | -1.38308 |
| 18 | 10.000 | 4.000 | -1.08123 |
| 19 | 13.333 | 4.000 | -1.02368 |
| 20 | 16.667 | 4.000 | -1.13009 |
| 21 | 20.000 | 4.000 | -0.61670 |
| 22 | 0.000 | 6.000 | -0.89921 |
| 23 | 3.333 | 6.000 | -1.79255 |
| 24 | 6.667 | 6.000 | -1.46076 |
| 25 | 10.000 | 6.000 | -1.14212 |
| 26 | 13.333 | 6.000 | -1.06278 |
| 27 | 16.667 | 6.000 | -1.11295 |
| 28 | 20.000 | 6.000 | -0.57194 |
| 29 | 0.000 | 8.000 | -0.91374 |
| 30 | 3.333 | 8.000 | -1.87353 |
| 31 | 6.667 | 8.000 | -1.55643 |
| 32 | 10.000 | 8.000 | -1.21803 |
| 33 | 13.333 | 8.000 | -1.09692 |
| 34 | 16.667 | 8.000 | -1.10185 |
| 35 | 20.000 | 8.000 | -0.54733 |
| 36 | 0.000 | 10.000 | -0.93748 |
| 37 | 3.333 | 10.000 | -1.94612 |
| 38 | 6.667 | 10.000 | -1.63355 |
| 39 | 10.000 | 10.000 | -1.27292 |
| 40 | 13.333 | 10.000 | -1.11987 |
| 41 | 16.667 | 10.000 | -1.10918 |
| 42 | 20.000 | 10.000 | -0.54496 |
| 43 | 0.000 | 12.000 | -0.43246 |
| 44 | 3.333 | 12.000 | -1.00745 |
| 45 | 6.667 | 12.000 | -0.83077 |
| 46 | 10.000 | 12.000 | -0.63080 |
| 47 | 13.333 | 12.000 | -0.56062 |
| 48 | 16.667 | 12.000 | -0.55713 |
| 49 | 20.000 | 12.000 | -0.26680 |
| | | | TOTAL = -48.3529 |

UNIVERSITY OF PUERTO RICO FILE NAME = EXAM1-6 .SOI PAGE 1

INTERVAL = 200 TIME = 0.040 DISTANCE 2.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.42253 |
| 2 | 3.333 | 0.000 | -0.49485 |
| 3 | 6.667 | 0.000 | -0.32217 |
| 4 | 10.000 | 0.000 | -0.32468 |
| 5 | 13.333 | 0.000 | -0.40447 |
| 6 | 16.667 | 0.000 | -0.51587 |
| 7 | 20.000 | 0.000 | -0.29093 |
| 8 | 0.000 | 2.000 | -1.12018 |
| 9 | 3.333 | 2.000 | -1.16034 |
| 10 | 6.667 | 2.000 | -0.59469 |
| 11 | 10.000 | 2.000 | -0.58242 |
| 12 | 13.333 | 2.000 | -0.79249 |
| 13 | 16.667 | 2.000 | -1.07458 |
| 14 | 20.000 | 2.000 | -0.64024 |
| 15 | 0.000 | 4.000 | -1.14812 |
| 16 | 3.333 | 4.000 | -1.26344 |
| 17 | 6.667 | 4.000 | -0.69803 |
| 18 | 10.000 | 4.000 | -0.65741 |
| 19 | 13.333 | 4.000 | -0.82161 |
| 20 | 16.667 | 4.000 | -1.06206 |
| 21 | 20.000 | 4.000 | -0.63381 |
| 22 | 0.000 | 6.000 | -1.11835 |
| 23 | 3.333 | 6.000 | -1.28831 |
| 24 | 6.667 | 6.000 | -0.76191 |
| 25 | 10.000 | 6.000 | -0.70528 |
| 26 | 13.333 | 6.000 | -0.84859 |
| 27 | 16.667 | 6.000 | -1.05622 |
| 28 | 20.000 | 6.000 | -0.62521 |
| 29 | 0.000 | 8.000 | -1.09400 |
| 30 | 3.333 | 8.000 | -1.27292 |
| 31 | 6.667 | 8.000 | -0.77230 |
| 32 | 10.000 | 8.000 | -0.74154 |
| 33 | 13.333 | 8.000 | -0.90221 |
| 34 | 16.667 | 8.000 | -1.11538 |
| 35 | 20.000 | 8.000 | -0.65713 |
| 36 | 0.000 | 10.000 | -1.01472 |
| 37 | 3.333 | 10.000 | -1.17599 |
| 38 | 6.667 | 10.000 | -0.75851 |
| 39 | 10.000 | 10.000 | -0.78193 |
| 40 | 13.333 | 10.000 | -0.96673 |
| 41 | 16.667 | 10.000 | -1.20618 |
| 42 | 20.000 | 10.000 | -0.71734 |
| 43 | 0.000 | 12.000 | -0.36866 |
| 44 | 3.333 | 12.000 | -0.50428 |
| 45 | 6.667 | 12.000 | -0.40835 |
| 46 | 10.000 | 12.000 | -0.43496 |
| 47 | 13.333 | 12.000 | -0.50346 |
| 48 | 16.667 | 12.000 | -0.61939 |
| 49 | 20.000 | 12.000 | -0.33941 |

TOTAL = -37.7842

INTERVAL = 400 TIME = 0.080 DISTANCE 4.000

| JOINT | X (FT) | Y (FT) | SOIL REACTION (KIPS) |
|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.32796 |
| 2 | 3.333 | 0.000 | -0.60134 |
| 3 | 6.667 | 0.000 | -0.43058 |
| 4 | 10.000 | 0.000 | -0.36768 |
| 5 | 13.333 | 0.000 | -0.40694 |
| 6 | 16.667 | 0.000 | -0.55214 |
| 7 | 20.000 | 0.000 | -0.34161 |
| 8 | 0.000 | 2.000 | -0.75647 |
| 9 | 3.333 | 2.000 | -1.35572 |
| 10 | 6.667 | 2.000 | -1.00389 |
| 11 | 10.000 | 2.000 | -0.75034 |
| 12 | 13.333 | 2.000 | -0.79503 |
| 13 | 16.667 | 2.000 | -1.11481 |
| 14 | 20.000 | 2.000 | -0.74475 |
| 15 | 0.000 | 4.000 | -0.78891 |
| 16 | 3.333 | 4.000 | -1.49550 |
| 17 | 6.667 | 4.000 | -1.16898 |
| 18 | 10.000 | 4.000 | -0.88948 |
| 19 | 13.333 | 4.000 | -0.88129 |
| 20 | 16.667 | 4.000 | -1.11125 |
| 21 | 20.000 | 4.000 | -0.68783 |
| 22 | 0.000 | 6.000 | -0.80338 |
| 23 | 3.333 | 6.000 | -1.63182 |
| 24 | 6.667 | 6.000 | -1.32880 |
| 25 | 10.000 | 6.000 | -1.03223 |
| 26 | 13.333 | 6.000 | -0.99085 |
| 27 | 16.667 | 6.000 | -1.12121 |
| 28 | 20.000 | 6.000 | -0.62603 |
| 29 | 0.000 | 8.000 | -0.81102 |
| 30 | 3.333 | 8.000 | -1.75803 |
| 31 | 6.667 | 8.000 | -1.49575 |
| 32 | 10.000 | 8.000 | -1.18180 |
| 33 | 13.333 | 8.000 | -1.08879 |
| 34 | 16.667 | 8.000 | -1.13424 |
| 35 | 20.000 | 8.000 | -0.58505 |
| 36 | 0.000 | 10.000 | -0.82828 |
| 37 | 3.333 | 10.000 | -1.86668 |
| 38 | 6.667 | 10.000 | -1.62842 |
| 39 | 10.000 | 10.000 | -1.29006 |
| 40 | 13.333 | 10.000 | -1.15878 |
| 41 | 16.667 | 10.000 | -1.16815 |
| 42 | 20.000 | 10.000 | -0.57756 |
| 43 | 0.000 | 12.000 | -0.38601 |
| 44 | 3.333 | 12.000 | -0.98625 |
| 45 | 6.667 | 12.000 | -0.84989 |
| 46 | 10.000 | 12.000 | -0.65810 |
| 47 | 13.333 | 12.000 | -0.59570 |
| 48 | 16.667 | 12.000 | -0.59878 |
| 49 | 20.000 | 12.000 | -0.27959 |
| | | | TOTAL = -45.0338 |

INTERVAL = 200 TIME = 0.040 DISTANCE 2.000

| JOINT | X (FT) | Y (FT) | DISPLACEMENT (FT) | ACELERATION (FT/SEG^2) |
|---|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.000019119 | -49.209 |
| 2 | 3.333 | 0.000 | -0.000047506 | -0.072 |
| 3 | 6.667 | 0.000 | -0.000042782 | 28.773 |
| 4 | 10.000 | 0.000 | 0.000015624 | -9.755 |
| 5 | 13.333 | 0.000 | 0.000037431 | -25.192 |
| 6 | 16.667 | 0.000 | 0.000002654 | 13.305 |
| 7 | 20.000 | 0.000 | -0.000042429 | 14.736 |
| 8 | 0.000 | 2.000 | 0.000006704 | -41.049 |
| 9 | 3.333 | 2.000 | -0.000052251 | 5.971 |
| 10 | 6.667 | 2.000 | -0.000042952 | 7.859 |
| 11 | 10.000 | 2.000 | 0.000011546 | -19.569 |
| 12 | 13.333 | 2.000 | 0.000034088 | -3.406 |
| 13 | 16.667 | 2.000 | 0.000008073 | 4.375 |
| 14 | 20.000 | 2.000 | -0.000035407 | 5.435 |
| 15 | 0.000 | 4.000 | 0.000005586 | -45.913 |
| 16 | 3.333 | 4.000 | -0.000049132 | -7.572 |
| 17 | 6.667 | 4.000 | -0.000045015 | 18.258 |
| 18 | 10.000 | 4.000 | 0.000005380 | -5.200 |
| 19 | 13.333 | 4.000 | 0.000033455 | -11.354 |
| 20 | 16.667 | 4.000 | 0.000012840 | -8.997 |
| 21 | 20.000 | 4.000 | -0.000031937 | 7.448 |
| 22 | 0.000 | 6.000 | 0.000005185 | -56.499 |
| 23 | 3.333 | 6.000 | -0.000044098 | -10.378 |
| 24 | 6.667 | 6.000 | -0.000044280 | 27.500 |
| 25 | 10.000 | 6.000 | 0.000001433 | 10.711 |
| 26 | 13.333 | 6.000 | 0.000032108 | -21.190 |
| 27 | 16.667 | 6.000 | 0.000011819 | -8.198 |
| 28 | 20.000 | 6.000 | -0.000034601 | 5.001 |
| 29 | 0.000 | 8.000 | -0.000016589 | -30.071 |
| 30 | 3.333 | 8.000 | -0.000051171 | -6.444 |
| 31 | 6.667 | 8.000 | -0.000040778 | 8.816 |
| 32 | 10.000 | 8.000 | 0.000003551 | -7.543 |
| 33 | 13.333 | 8.000 | 0.000028761 | -10.487 |
| 34 | 16.667 | 8.000 | 0.000005973 | 5.093 |
| 35 | 20.000 | 8.000 | -0.000041555 | 16.589 |
| 36 | 0.000 | 10.000 | -0.000034472 | -13.679 |
| 37 | 3.333 | 10.000 | -0.000057119 | 4.888 |
| 38 | 6.667 | 10.000 | -0.000039489 | -0.841 |
| 39 | 10.000 | 10.000 | 0.000004247 | -13.180 |
| 40 | 13.333 | 10.000 | 0.000026969 | -1.916 |
| 41 | 16.667 | 10.000 | 0.000003373 | 8.539 |
| 42 | 20.000 | 10.000 | -0.000044710 | 12.641 |
| 43 | 0.000 | 12.000 | -0.000035917 | -21.455 |
| 44 | 3.333 | 12.000 | -0.000056070 | -10.667 |
| 45 | 6.667 | 12.000 | -0.000044411 | 30.816 |
| 46 | 10.000 | 12.000 | 0.000000972 | 12.937 |
| 47 | 13.333 | 12.000 | 0.000030773 | -26.445 |
| 48 | 16.667 | 12.000 | 0.000007397 | -10.295 |
| 49 | 20.000 | 12.000 | -0.000043322 | 11.446 |

INTERVAL = 200 TIME = 0.040 DISTANCE 2.000

VEHICLE COORDINATES DISPLACEMENTS

| COORDINATE | DISPLACEMENT (FT) | ACELERATION (FT/SEG^2) |
|---|---|---|
| 50 | -0.2823899 | -12.5383463 |
| 51 | -0.0011917 | -0.2184160 |
| 52 | 0.0000028 | -0.0185978 |
| 53 | -0.0616840 | 46.6565666 |
| 54 | -0.0535258 | 8.7769899 |
| 55 | -0.1061397 | -5.3862419 |
| 56 | -0.1061412 | -5.3980532 |

INTERVAL = 400     TIME = 0.080     DISTANCE 4.000

| JOINT | X (FT) | Y (FT) | DISPLACEMENT (FT) | ACELERATION (FT/SEG^2) |
|---|---|---|---|---|
| 1 | 0.000 | 0.000 | -0.000096314 | -25.459 |
| 2 | 3.333 | 0.000 | -0.000113784 | 9.546 |
| 3 | 6.667 | 0.000 | -0.000071108 | 19.140 |
| 4 | 10.000 | 0.000 | 0.000023007 | -10.292 |
| 5 | 13.333 | 0.000 | 0.000073335 | -26.686 |
| 6 | 16.667 | 0.000 | 0.000027395 | 2.369 |
| 7 | 20.000 | 0.000 | -0.000066418 | 25.895 |
| 8 | 0.000 | 2.000 | -0.000109303 | 31.936 |
| 9 | 3.333 | 2.000 | -0.000118621 | 34.317 |
| 10 | 6.667 | 2.000 | -0.000075547 | 28.594 |
| 11 | 10.000 | 2.000 | 0.000013850 | -7.859 |
| 12 | 13.333 | 2.000 | 0.000063541 | -25.237 |
| 13 | 16.667 | 2.000 | 0.000021301 | -8.875 |
| 14 | 20.000 | 2.000 | -0.000069636 | 21.630 |
| 15 | 0.000 | 4.000 | -0.000111946 | 22.219 |
| 16 | 3.333 | 4.000 | -0.000111815 | 5.912 |
| 17 | 6.667 | 4.000 | -0.000074551 | 27.957 |
| 18 | 10.000 | 4.000 | 0.000006686 | -0.854 |
| 19 | 13.333 | 4.000 | 0.000055557 | -22.208 |
| 20 | 16.667 | 4.000 | 0.000015010 | 5.601 |
| 21 | 20.000 | 4.000 | -0.000072431 | 7.672 |
| 22 | 0.000 | 6.000 | -0.000121474 | -20.426 |
| 23 | 3.333 | 6.000 | -0.000109551 | -23.150 |
| 24 | 6.667 | 6.000 | -0.000073062 | 10.829 |
| 25 | 10.000 | 6.000 | 0.000001353 | -0.935 |
| 26 | 13.333 | 6.000 | 0.000049390 | -26.082 |
| 27 | 16.667 | 6.000 | 0.000011872 | -0.070 |
| 28 | 20.000 | 6.000 | -0.000076390 | 32.329 |
| 29 | 0.000 | 8.000 | -0.000156352 | 59.837 |
| 30 | 3.333 | 8.000 | -0.000132205 | 13.000 |
| 31 | 6.667 | 8.000 | -0.000083067 | 19.953 |
| 32 | 10.000 | 8.000 | -0.000005589 | -1.259 |
| 33 | 13.333 | 8.000 | 0.000043027 | -15.445 |
| 34 | 16.667 | 8.000 | 0.000011897 | -0.384 |
| 35 | 20.000 | 8.000 | -0.000073159 | 23.756 |
| 36 | 0.000 | 10.000 | -0.000184004 | 50.087 |
| 37 | 3.333 | 10.000 | -0.000151294 | 16.902 |
| 38 | 6.667 | 10.000 | -0.000094102 | 21.685 |
| 39 | 10.000 | 10.000 | -0.000013305 | 3.773 |
| 40 | 13.333 | 10.000 | 0.000038572 | -16.157 |
| 41 | 16.667 | 10.000 | 0.000015181 | -13.808 |
| 42 | 20.000 | 10.000 | -0.000063977 | 25.534 |
| 43 | 0.000 | 12.000 | -0.000196495 | 22.687 |
| 44 | 3.333 | 12.000 | -0.000158542 | 7.113 |
| 45 | 6.667 | 12.000 | -0.000102329 | 26.345 |
| 46 | 10.000 | 12.000 | -0.000019790 | 6.310 |
| 47 | 13.333 | 12.000 | 0.000035861 | -9.923 |
| 48 | 16.667 | 12.000 | 0.000018560 | 1.482 |
| 49 | 20.000 | 12.000 | -0.000050383 | 1.192 |

INTERVAL = 400 TIME = 0.080 DISTANCE 4.000

VEHICLE COORDINATES DISPLACEMENTS

| COORDINATE | DISPLACEMENT (FT) | ACELERATION (FT/SEG^2) |
|---|---|---|
| 50 | -0.3125502 | -9.8846874 |
| 51 | -0.0018504 | -0.4244176 |
| 52 | 0.0000009 | 0.0462096 |
| 53 | -0.0191168 | -106.2856600 |
| 54 | -0.0396572 | 9.7815361 |
| 55 | -0.1171834 | -4.3871613 |
| 56 | -0.1171893 | -4.3756075 |

STEP NUMBER 1887

| ELEMENT | | SUB-ELEMENT # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | # 8 | # 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOP | none | none | none | none | none | none | none | none | ONE |
| 32 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| | TOP | none | none | none | none | none | none | none | none | ONE |
| 38 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 179.9 |

STEP NUMBER 1888

| ELEMENT | | SUB-ELEMENT # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | # 8 | # 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOP | none | none | none | ONE | none | none | none | none | ONE |
| 20 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 0.0 | 1.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| | TOP | none | none | none | none | ONE | none | none | none | ONE |
| 50 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 0.0 | 0.0 | 178.1 | 0.0 | 0.0 | 0.0 | 179.5 |

STEP NUMBER 1889

| ELEMENT | | SUB-ELEMENT # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | # 8 | # 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOP | ONE | none | none | none | none | none | none | none | none |
| 2 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | -186.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | TOP | none | none | none | none | none | none | none | none | ONE |
| 8 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -0.6 |
| | TOP | none | none | ONE | none | none | none | none | none | none |
| 14 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | -182.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | TOP | none | none | ONE | none | none | none | none | none | none |
| 26 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | -179.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | TOP | ONE | none | none | none | none | none | none | none | none |
| 44 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | -0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | TOP | ONE | none | none | none | none | none | none | none | none |
| 56 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| | TOP | none | none | none | none | none | none | none | none | ONE |
| 62 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 180.6 |
| | TOP | none | none | ONE | none | none | none | none | none | none |
| 68 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 6.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

STEP NUMBER 1890

SUB-ELEMENT

| ELEMENT | | # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | # 8 | # 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOP | none | none | none | ONE | none | none | none | none | ONE |
| 32 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 0.0 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |
| | TOP | none | none | none | none | ONE | none | none | none | ONE |
| 38 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 0.0 | 0.0 | 178.4 | 0.0 | 0.0 | 0.0 | 179.8 |

STEP NUMBER 2037

SUB-ELEMENT

| ELEMENT | | # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | # 8 | # 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOP | none | none | ONE | none | none | none | none | none | ONE |
| 8 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | -10.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 75.9 |
| | TOP | ONE | none | none | none | none | none | none | none | ONE |
| 62 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 190.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 104.2 |

STEP NUMBER 2038

SUB-ELEMENT

| ELEMENT | | # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | # 8 | # 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOP | none | none | ONE | none | none | ONE | none | none | none |
| 14 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | -188.5 | 0.0 | 0.0 | -180.5 | 0.0 | 0.0 | 0.0 |
| | TOP | ONE | none | none | none | none | none | ONE | none | none |
| 56 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 8.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 0.0 |

STEP NUMBER 2039

SUB-ELEMENT

| ELEMENT | | # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | # 8 | # 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOP | none | none | ONE | none | none | none | none | none | ONE |
| 26 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | -180.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | -180.1 |
| | TOP | ONE | none | none | none | none | none | none | none | ONE |
| 44 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 |

STEP NUMBER 2105

SUB-ELEMENT

| ELEMENT | | # 1 | # 2 | # 3 | # 4 | # 5 | # 6 | # 7 | # 8 | # 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| | TOP | ONE | none | none | none | none | ONE | none | none | none |
| 2 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | -189.3 | 0.0 | 0.0 | 0.0 | 0.0 | -188.4 | 0.0 | 0.0 | 0.0 |
| | TOP | none | none | ONE | none | none | none | ONE | none | none |
| 68 | BOTTOM | none | none | none | none | none | none | none | none | none |
| | ANGLE | 0.0 | 0.0 | 9.3 | 0.0 | 0.0 | 0.0 | 8.5 | 0.0 | 0.0 |